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AUTO-PROCESSING OF OTH RADAR AMPLITUDE/RANGE/DOPPLER DATA

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A synoptic data collection effort was begun using the East Coast Radar System (ECRS), as part of Air Force investigations of equatorial ionospheric clutter. Due to the volume of data, an automatic processing scheme has been developed to characterize radar Doppler frequency spectra in terms of a small number of parameters. These parameters allow reconstruction of reasonable facsimiles of the original spectra, and facilitate a comprehensive statistical analysis. A data compression algorithm has also been implemented to provide smoothing and further data reduction. This report describes the compression and processing algorithms, and presents some results from the January, 1992 data campaign.

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Radar, Ionospheric clutter, Equatorial clutter, Data processing, Over-the-horizon (OTH), Data reduction, Amplitude-range-doppler (ARD) data, East coast radar system (ECRS)

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1. INTRODUCTION

As part of the Air Force program to investigate the characteristics of the equatorial ionospheric clutter as seen by the US OTH-B radar systems, particularly at night, a synoptic data collection effort was begun using the East Coast Radar System (ECRS). This system was operated on a routine non-interference basis to collect radar data during each operational period, usually about six to eight hours per day. The system was limited to one radar segment - usually Segment III, covering a sixty degree azimuth from 136.5° T to 196.5° T, looking southward over South America.

The primary data, the so-called ARD (amplitude-range-Doppler) data, containing all the radar backscattered energy as a function of range and within each range bin a full Doppler frequency spectrum, was recorded at the Bangor site on standard 9-track computer tapes. When the radar is operating well, these spectra are dominated by the strong sea clutter return at or near zero Doppler frequency, as illustrated in Figure 1. The radar typically processes a 518 nm barrier at a selected range start of about 1000 nm, though this can be varied from 500 nm to 1500 nm. Each Doppler spectrum covers the frequency range from -WRF/2 to +WRF/2. Typically the WRF is in the range from 30 to 40 Hz, and assuming a nighttime operating frequency of 15 MHz, the Doppler spectrum covers the velocity range from -300 m/s to +300 m/s. Aircraft target backscatter signals appear somewhere within this spectrum against a background of wideband atmospheric noise. Under favorable conditions, sea clutter returns vary from 50 to 80 dB above the noise level while the target signal is 5 to 15 dB above noise.

A complication arises when another form of clutter appears which is Doppler spread and often easily obscures the relatively small target signal. This clutter originates by scatter from ionospheric irregularities which are in random motion with sufficiently large velocities to fill up a significant portion of the available Doppler spectrum used for target detection. This situation is illustrated in Figure 2 where the ionospheric clutter signal is often triangular in shape and peaks near zero Doppler, though the peak can be shifted either towards positive or negative Doppler frequencies.

This triangular clutter is termed moderate spreading, filling only a portion of the available spectrum. A second form of ionospheric clutter is sufficiently wide spread so that it appears as "white" as atmospheric noise and can be detected only by comparing the noise level with the radar transmitters off to when they are on. A significant change, often larger than 10 dB, indicates the presence of this wideband clutter which degrades the performance of the radar as well as, if not more than, the moderately spread clutter.

With one years data in storage on about 1000 magnetic tapes, it quickly became apparent that in order to process any significant fraction of these data, an automatic scheme would have to be developed that would characterize these many spectra in terms of a small number of parameters that would permit a comprehensive statistical analysis. It was decided to keep the number of these parameters reasonably small and yet be able to characterize each spectrum and even to

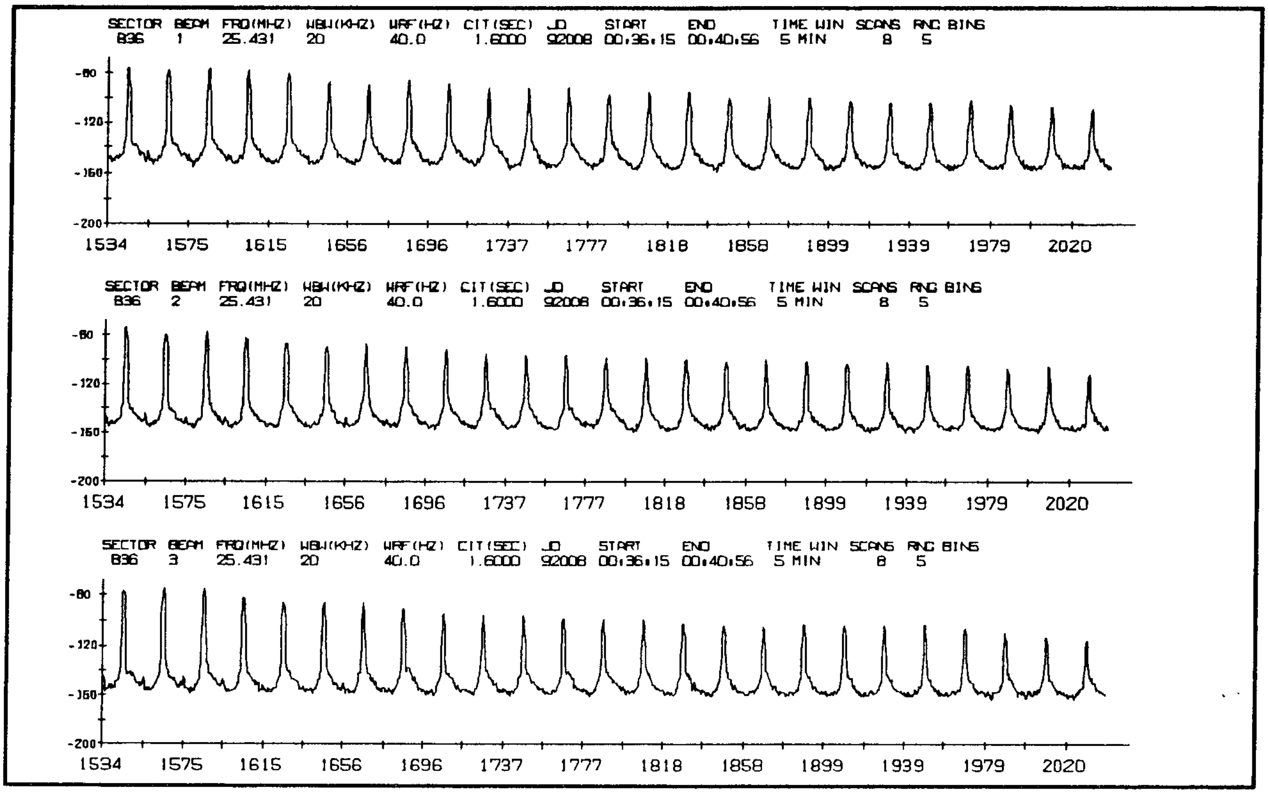


Figure 1 Strong Sea Clutter

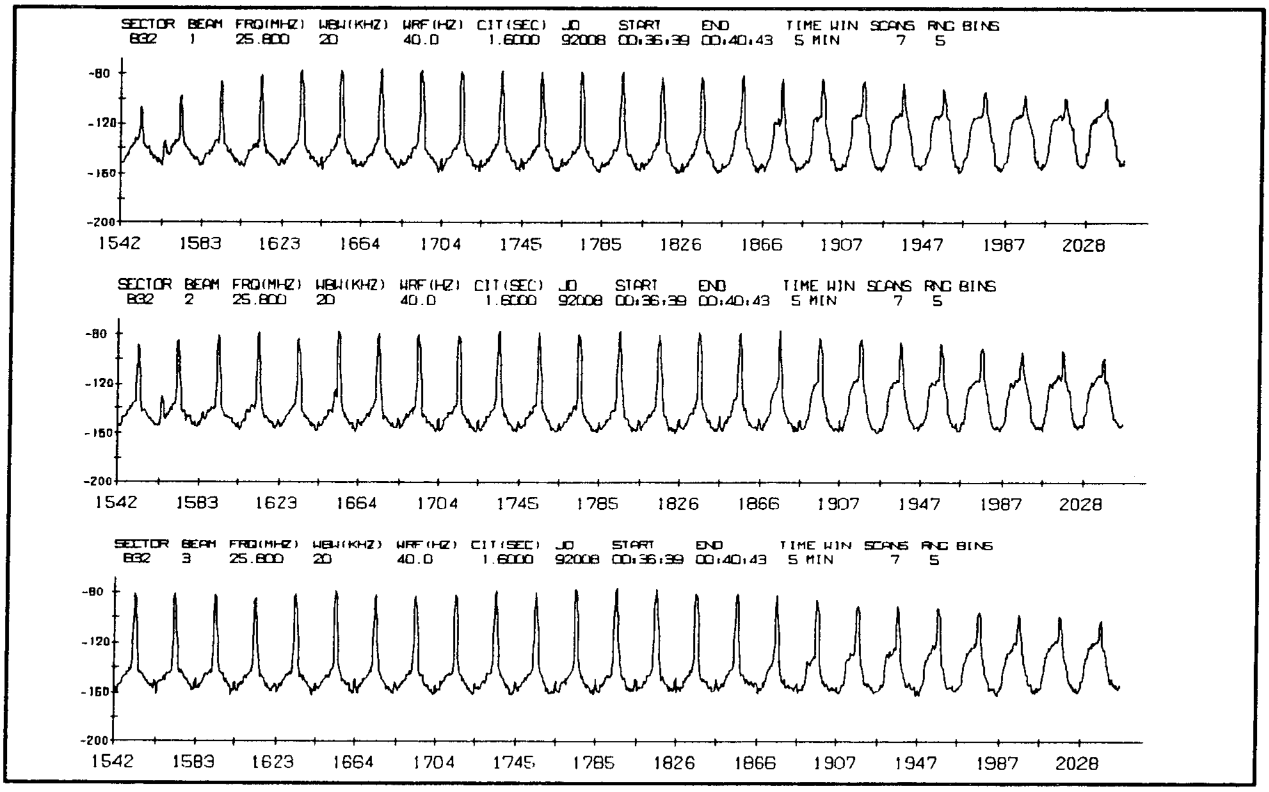


Figure 2 Ionospheric Clutter

reconstruct a reasonable facsimile of the original spectrum using only these parameters. To remove some of the high variability in these spectra caused by noise, targets, and other factors, it was decided to smooth these data by averaging over five adjacent range bins and over five minutes in time. This time averaging involves some five to seven spectra depending on the revisit time to a particular beam position, typically on the order of 40 to 60 seconds. Besides the obvious smoothing that results from this averaging process, there is also a concomitant reduction by a factor of about 25 in the volume of data with little loss in information for purposes of synoptic analysis.

The basic set of eight parameters, schematically depicted in Figure 3 [*Sales*, 1992], is:

a. ground clutter peak amplitude
b. ground clutter peak Doppler frequency shift
c. transmitter-on noise level
d. transmitter-off noise level
e. ionospheric clutter peak amplitude
f. ionospheric clutter peak Doppler frequency shift
g. slope on the positive Doppler side of the ionospheric clutter
h. slope on the negative Doppler side of the ionospheric clutter

This basic set of parameters is supplemented whenever special problems appear in the ARD data. For example, when the transmitter-on noise level appears to increase as a function of range, the noise level in each range bin is determined and recorded separately. These and other special cases are discussed in the latter sections of this report.

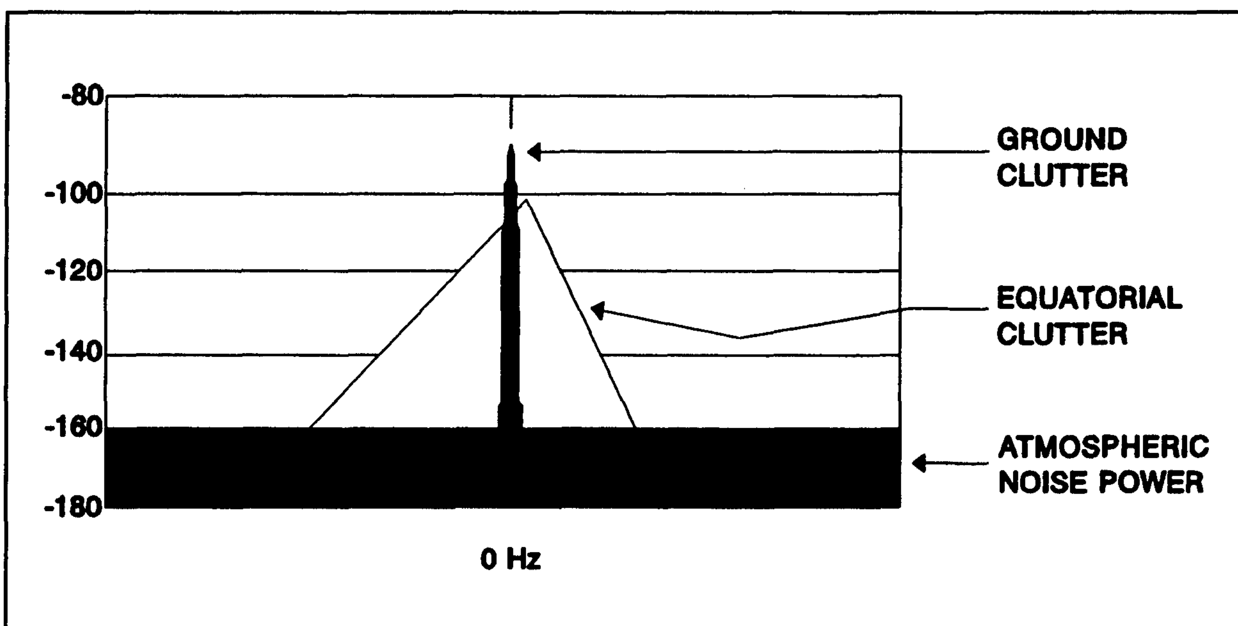


Figure 3 Schematic of Equatorial Backscatter Doppler Spectrum

2. APPROACH

2.1 ARD DATA PROCESSING OVERVIEW

Figure 4 shows an outline of the ARD data processing scheme. Details of the tape dump and file structure conversion steps have been reported [*Reynolds*, 1993]. The data compression and auto-processing steps are discussed in detail in the following sections.

The auto-processing algorithm described below is designed to model these spectra with a small set of numeric parameters that may be used to reproduce a reasonable likeness of the original data. Collections of these parameters taken from large data samples may then be used for synoptic studies of ionospheric and radar phenomena over extended time periods.

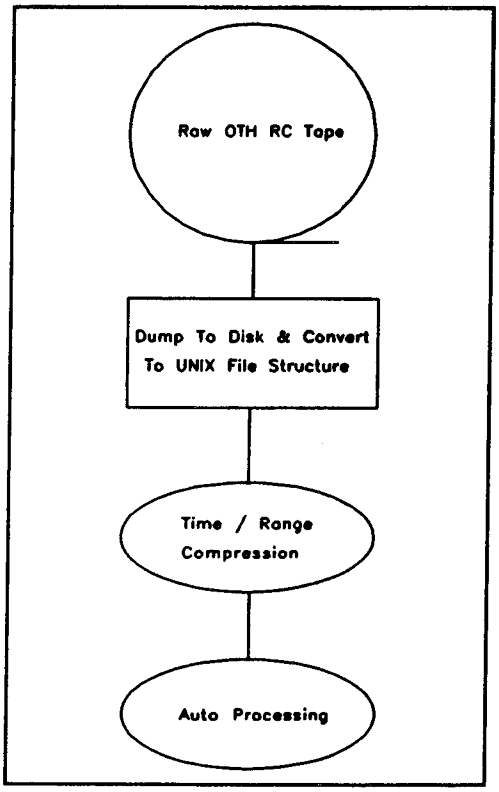


Figure 4 ARD Processing Overview

2.2 DATA COMPRESSION

2.2.1 Range Averaging

The principal requirement for the effective implementation of an automatic ARD data processing algorithm is a reasonably smooth data set. In general, raw ARD data spectra are fairly noisy, particularly in areas of low signal strength (noise region). Figures 5 and 6 show two examples of typical ARD spectra from East Coast Radar System (ECRS) sector 3-8, taken approximately five minutes apart; here each 512 nm spectrum is shown divided into four range segments. Some important radar operating parameters are summarized along the top, with beam locations indicated at the right edge. Range is marked in nautical miles on the abscissa, while the ordinates indicate received power in decibels. Although the ground clutter "spikes" are well defined, the remaining portions of these spectra contain many local variations.

An averaging process has been developed to smooth out these fluctuations, and at the same time, reduce the volume of data. For each of the three receive beams in a sector, bins are defined containing five range cells. The data in these bins are then averaged and treated as if they occur at a common range. Median values are taken at every Doppler line (the discrete points) within the bin to produce a composite spectrum at the range cell. Since the total number of range bins is not an exact multiple of five, there are always some range bins at the end of the spectra that are ignored. For example, a 64 range bin processing is reduced to 12 averaged range bins, with 4 bins discarded. Figures 7 and 8 show the results of this range averaging applied to the data

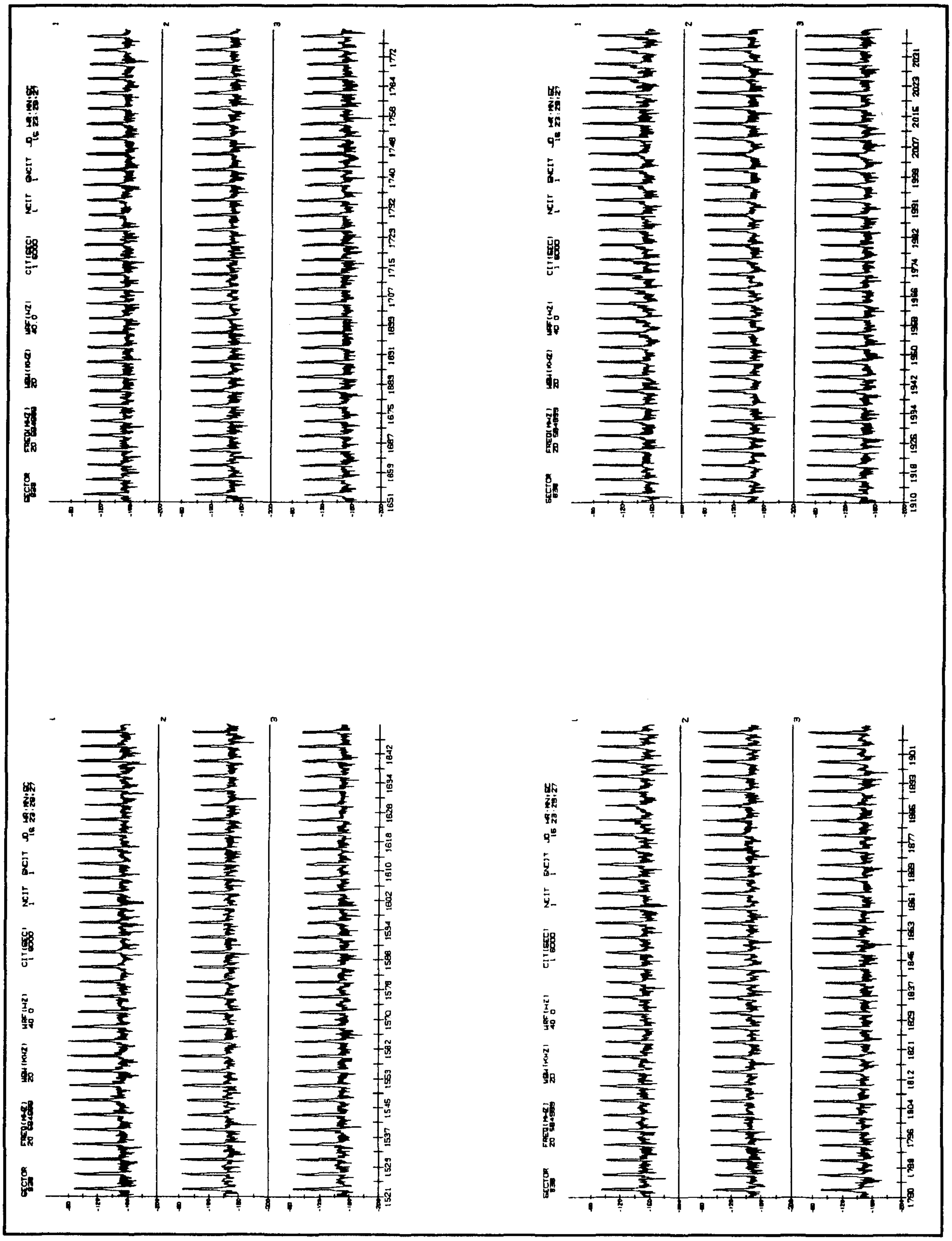


Figure 5 Raw ARD Data: Sector 3-8, 16 Jan 1992, 23:29:27

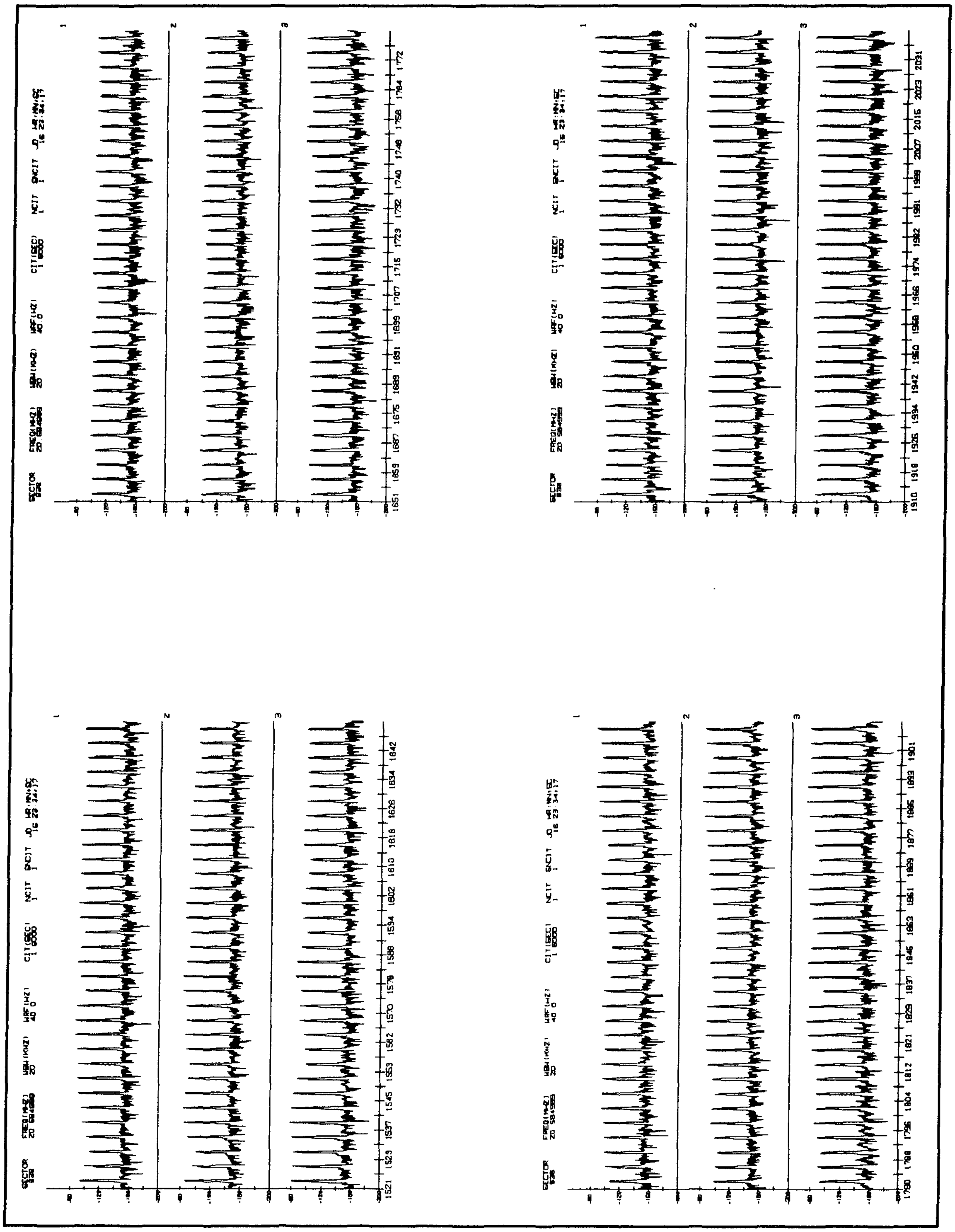


Figure 6 Raw ARD Data: Sector 3-8, 16 Jan 1992, 23:34:17

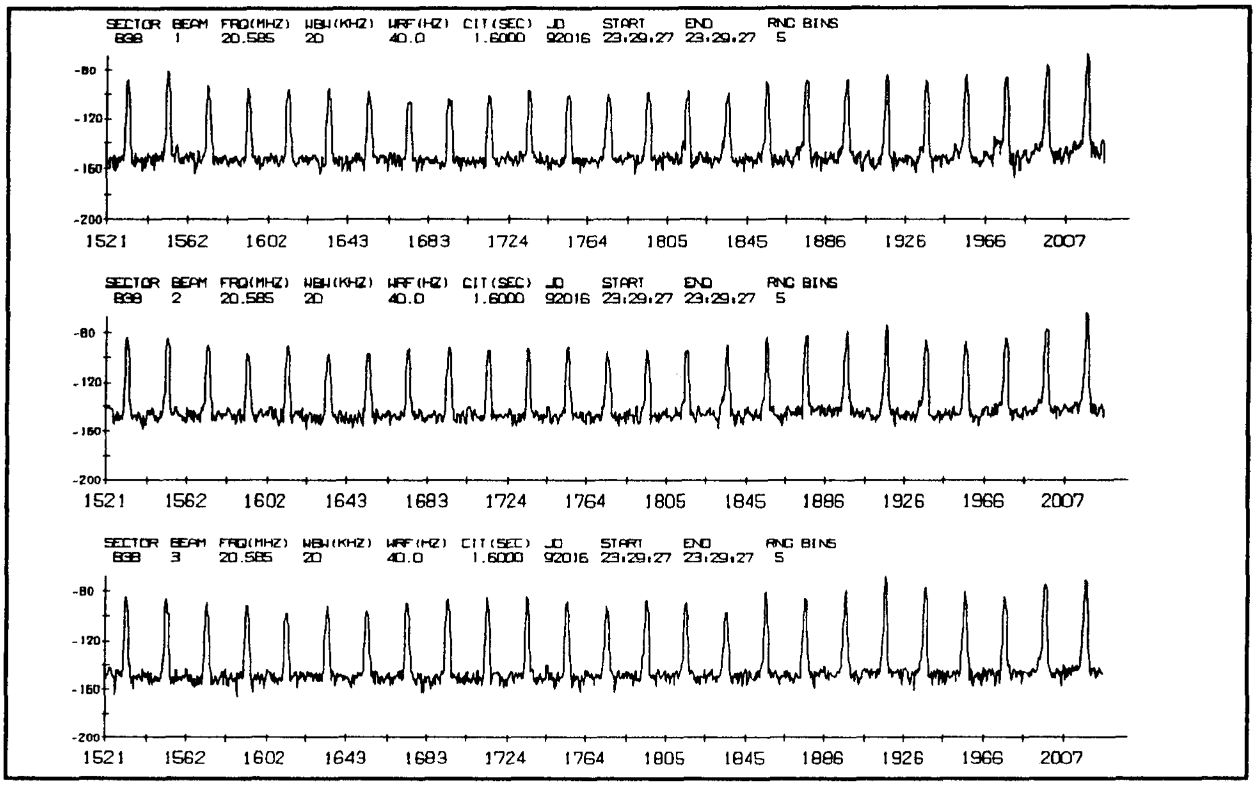


Figure 7 Range Averaged ARD Data: Sector 3-8, 16 Jan 1992, 23:29:27

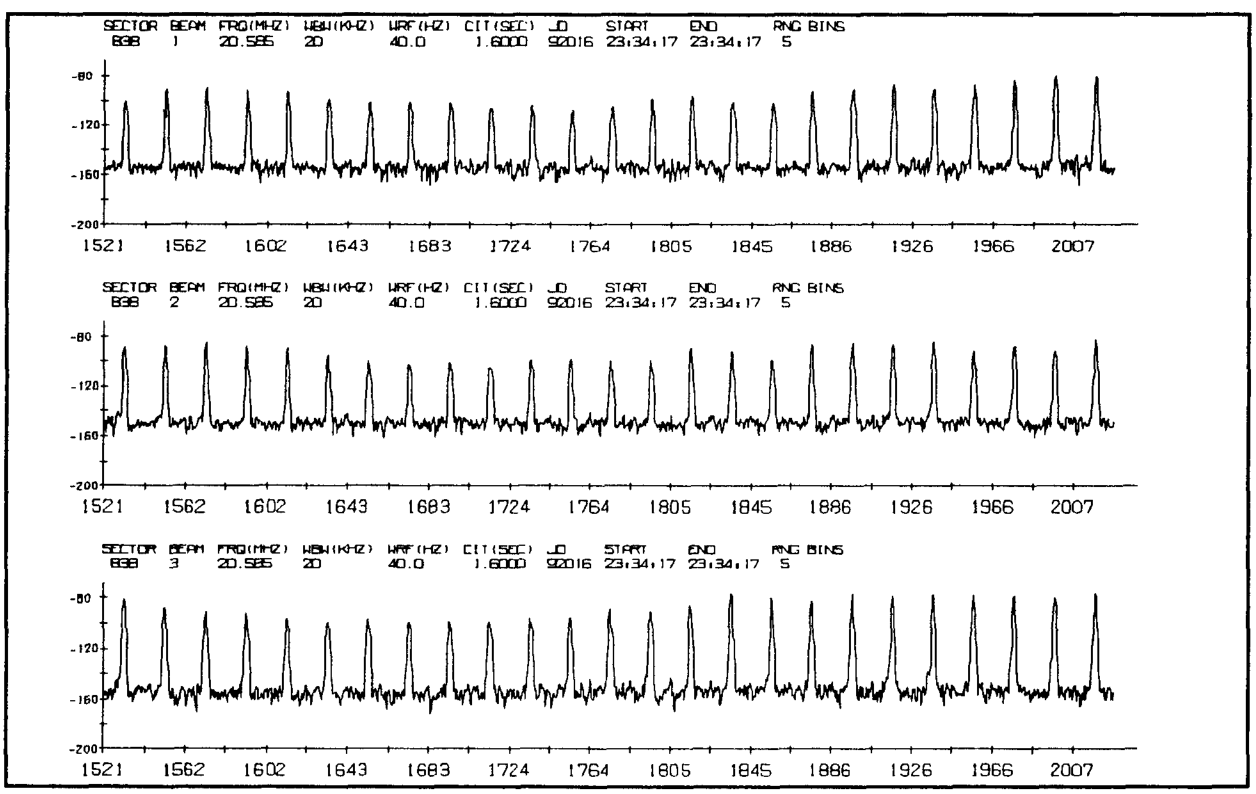


Figure 8 Range Averaged ARD Data: Sector 3-8, 16 Jan. 1992, 23:34:17

shown in Figures 5 and 6. This range averaging results in compression by a factor of five.

2.2.2 Time Averaging

Although the range averaged data is much smoother than the raw data, sufficient fluctuations still occur to make processing difficult. Consequently, time averaging has been implemented for further smoothing and for further data reduction. In this case, **mean** values are taken from all scans in a receive beam and range bin within a five minute window. The ARD headers are monitored so that only data with common operating parameters are combined. Specifically, accumulated data is dumped and a fresh mean calculation is initiated if a change is detected in any of the following:

- Starting slant range (allowed to vary by one fourth of a range cell)
- Primary WRF
- Primary CIT
- Number of range cells
- Number of Doppler cells
- Operating frequency (allowed to vary by 1 MHz)

These parameters are monitored separately for each sector. When more than one mean is obtained in a given beam within a single five minute window, the mean computed from the largest number of scans is taken as representative and the other data is discarded.

Time averaged data for Sector 3-8 incorporating seven separate scans, including the two shown in Figures 7 and 8, are displayed in Figure 9. Some irregularities remain, particularly in the noise region. However, these data are clearly much smoother than the range averaged data in Figures 7 and 8, and therefore are more suitable for automatic processing. Note that the important features of the raw spectra are preserved in the averaged data. Extensive comparisons of averaged and unaveraged data have indicated that this is generally true.

2.2.3 Processing Requirements

There are several requirements that must be met for data to be included in the averaging process:

- Only barrier and interrogate beam data are considered. Support barrier and support interrogate beams are used for transmitter-off noise level determination.

- Barrier and interrogate beams with transmitter power reduction of 50 dB are not included (this is the transmitter-off condition).

- If blind speed unmasking is active, only the primary beam is processed.

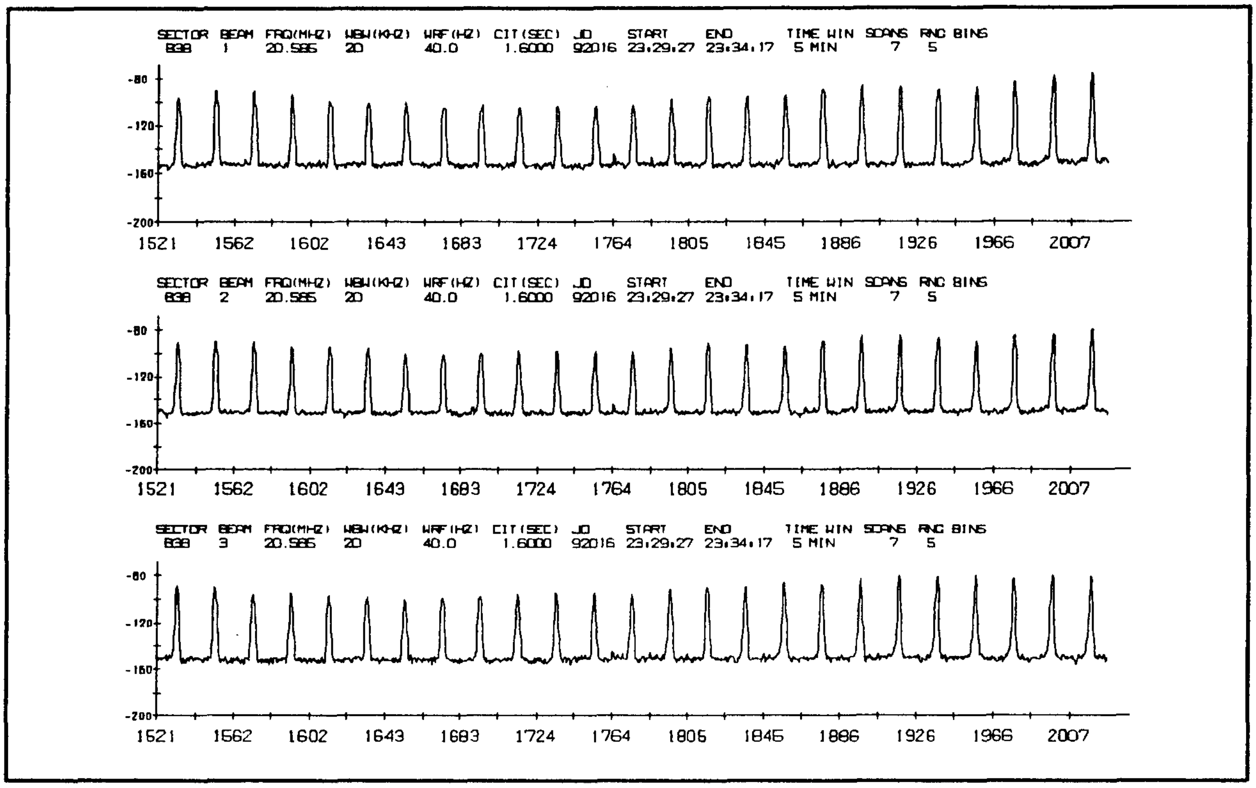


Figure 9 Time Averaged ARD Data: Sector 3-8, 16 Jan 1992, 23:29:27 - 23:34:17

2.2.4 Transmitter-Off Noise Level

During the averaging process, support beam header data is monitored for data with a transmitter power reduction of 50 dB (indicating transmitter-off status). When such a scan is found, the first four points and the last three points in all range cells are collected and sorted. The median value is then saved in a separate transmitter-off data list, along with the corresponding time, WRF, CIT, WBW, and operating frequency.

Upon completion of the averaging process, a separate pass is made through the averaged data to find the closest match to the transmitter-off data list. There are no requirements for WRF, CIT, or WBW; however, the operating frequencies in the two data sets may differ by no more than 1 MHz. If more than one suitable transmitter-off entry exists for an averaged scan, the one with the time closest to that of the averaged data is used.

2.3 CHARACTERISTICS OF ARD SPECTRA

As previously stated, one fundamental objective of the synoptic study is to summarize the structure of a range cell with a small set of parameters. Some basic characteristics of the ARD data that are of interest for the synoptic study are defined as follows:

- Ground clutter amplitude (GCA) - the peak amplitude within an individual range cell.

- Ground clutter Doppler (GCD) - the velocity (v_r) associated with the ground clutter amplitude, calculated from

$$v_r = \frac{cf_D}{2f_o}$$

  where f_D is the Doppler frequency at the peak, within the range of +WRF/2 to -WRF/2 for the particular range cell, and f_o is the operating frequency.

- Ionospheric clutter amplitude (ICA) - the peak amplitude of the ionospheric clutter (generally the largest point other than the data associated with the ground clutter "spike").

- Ionospheric clutter Doppler (ICD) - the velocity associated with the ionospheric clutter peak amplitude, obtained by the same method as the ground clutter Doppler.

- Median noise level (MNL) - For transmitter-on data, the median value of the first Doppler frequencies points and the last three Doppler frequencies from each range cell. Although this definition of the median noise level is suitable to most ARD spectra, several exceptional cases occur on a fairly regular basis. These exceptions are discussed in Section 2.4.2.

2.4 ARD PROCESSING

An overview of the ARD auto-processing procedure is shown in Figure 10. Note that the ground clutter and noise level searches are completed before any ground clutter excision is performed. Aside from some minor considerations discussed below, each range cell is processed independently.

2.4.1 Ground Clutter Excision Window Determination

Finding the ground clutter peak point is a fairly straightforward task, consisting of a search for the largest value in the central region of a range cell. Specifically, the algorithm restricts its search to points within a ± 25 m/s Doppler velocity of the middle of the cell. In most cases, the resulting point is also the largest value for the entire range cell. However, larger values may occur outside the central region in exceptional circumstances; such an example is shown in Section 3.1. This search results in the peak ground clutter amplitude and the Doppler frequency at the peak.

Once the ground clutter peak has been found, a ground clutter excision window is defined by

removing all points with Doppler velocities within a velocity region about the located peak. The width of this region is adjustable, and is usually set to ±25 m/s. A variety of excision velocities have been examined, ranging from 20 m/s to 40 m/s. Our tests have suggested that a velocity of 25 m/s provides the best compromise; other values tend either to leave too much ground clutter, or to remove critical ionospheric clutter data.

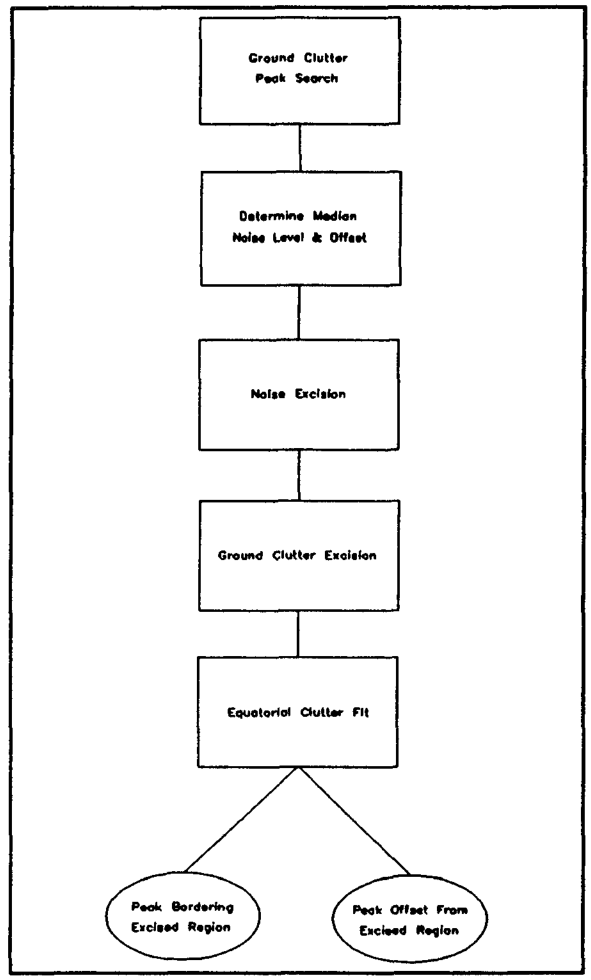


Figure 10 ARD Auto-Processing Procedure

The number of points discarded on either side of the peak is calculated from

$$\frac{NDC*2v_{EX}*f_o}{WRF*c}$$

where NDC is the number of Doppler bins per range cell, v_{EX} is the excision velocity, f_0 is the operating frequency, and c is the speed of light.

Two additional refinements are then made to the basic search:

- The differences between the peak point and the two immediately adjacent points are found. If one of these amplitude differences is more than twice the other, and the smaller difference is less than 3 dB, it is assumed that the data has a "flat" peak. The excision window is then shifted toward the "flat" area by one Doppler line.

- The excision window is scanned from the peak point out to the edges. If two consecutive increasing points are encountered, the window is narrowed to the bottom of the "notch". This prevents unwanted excision of ionospheric clutter data located close to the ground clutter. A typical "notch" case is shown in Figure 11.

2.4.2 Median Noise Level Determination

This algorithm recognizes two basic types of noise, which are computed initially:

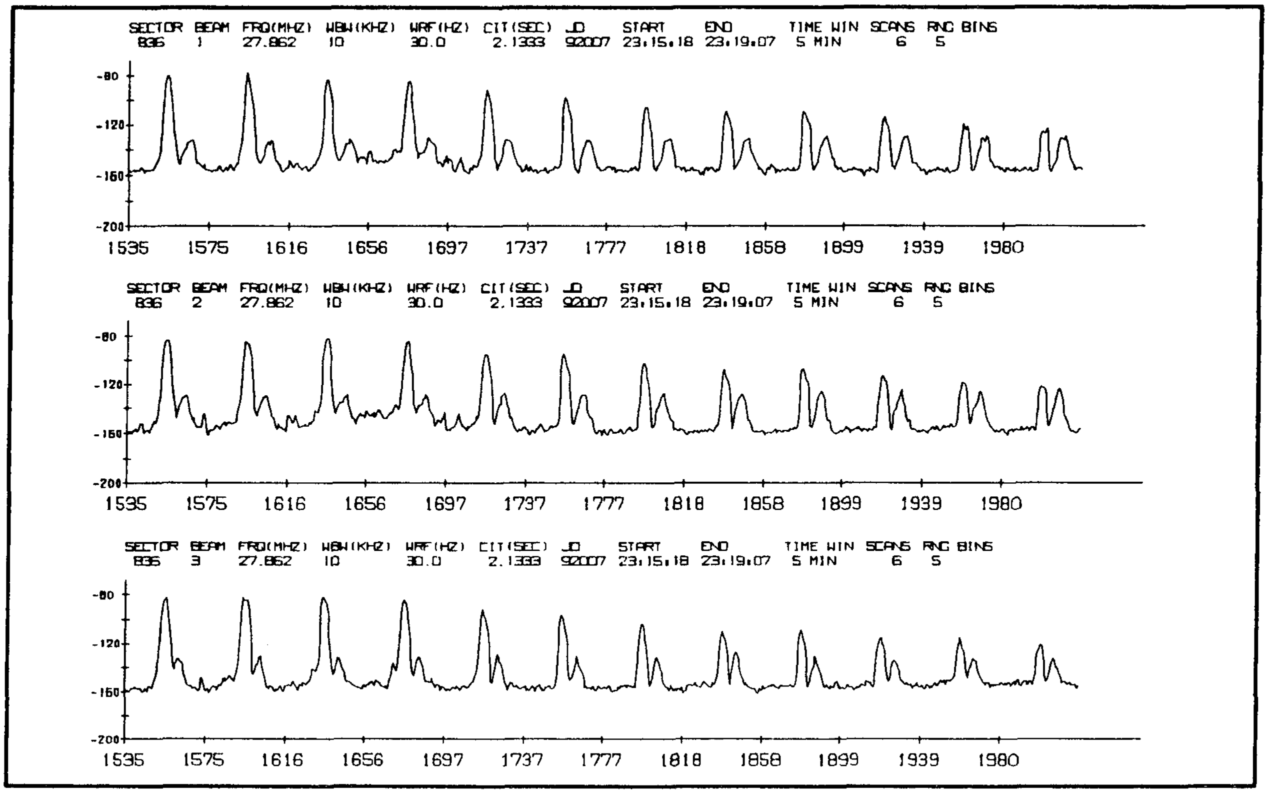


Figure 11 Ground Clutter "Notch"

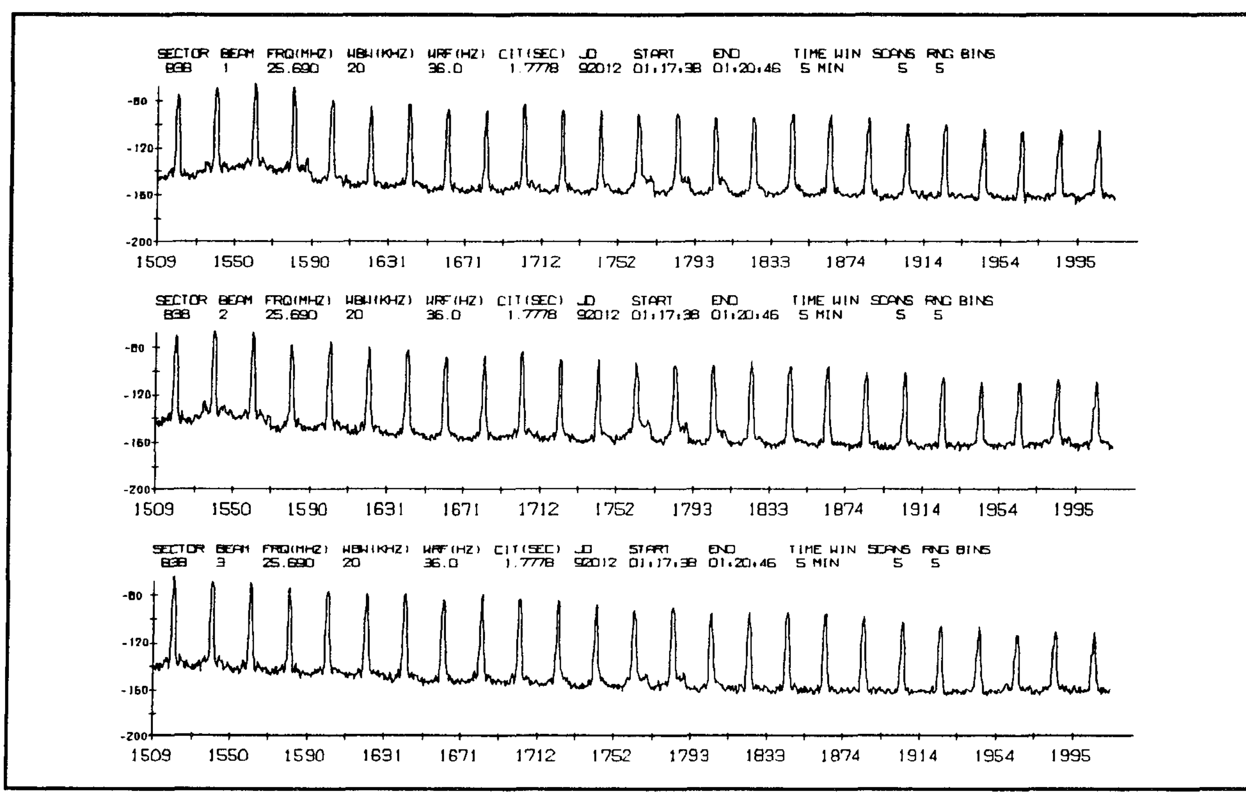


Figure 12 Outer Noise

- "Outer" noise - the median of the first four and the last three points in each range cell.

- "Inner" noise - the median of the seven smallest points in a range cell, regardless of position.

The indices of the seven data points corresponding to the inner noise are saved and sorted by Doppler frequency. If five of the seven remaining indices lie within a Doppler range of one quarter of the WRF, then the inner noise is considered to be "clustered". The middle index of the seven points is taken as the inner noise location. An example of outer noise is shown in Figure 12, where the lowest values are concentrated at the range cell boundaries. Figure 13 is a good example of inner noise data, particularly at the higher ranges in beams 2 and 3.

If the inner noise level is clustered and is at least 3 dB below the outer noise level, the median noise level is set at the inner noise level and the processing range is offset so that the inner noise location is located on the new range cell boundary. The 3 dB tolerance is allowed, since the inner noise can never exceed the outer noise. If the inner noise level does not satisfy the above criteria, the outer noise level is used as the median noise level, and data is processed based on the normal range cell boundaries.

Once the noise level has been established, the median values of the five points at each end of the processing range are calculated. If these two medians differ by more than 3 dB, they are used to determine a noise slope. Although the noise slope is generally small, sharply sloped noise levels do occur. An example of such a case is shown in Figure 14, where increasing noise is seen at higher ranges in all three beams.

2.4.3 Noise and Ground Clutter Excision

Once the excision criteria have been established, all data within the ground clutter excision window is removed. Then the data is scanned from the excision window boundaries to the processed cell boundaries until several consecutive points are found within a given tolerance of the median noise level (the specific number of points is adjustable). Again, a number of test runs were made to determine optimal parameters. We have obtained our best results using a three point "noise barrier" and a tolerance of 4 dB above the median noise level.

After the "noise barrier" is found, the noise excision regions on each side of the ground clutter peak are scanned separately. If more than half of the data points to be excised are above the noise threshold, then the data in the noise region is retained. This situation usually indicates the presence of ionospheric clutter that is well offset from the ground clutter. Figure 15 shows a number of range cells in which there are several noise points separating the ionospheric clutter from the ground clutter.

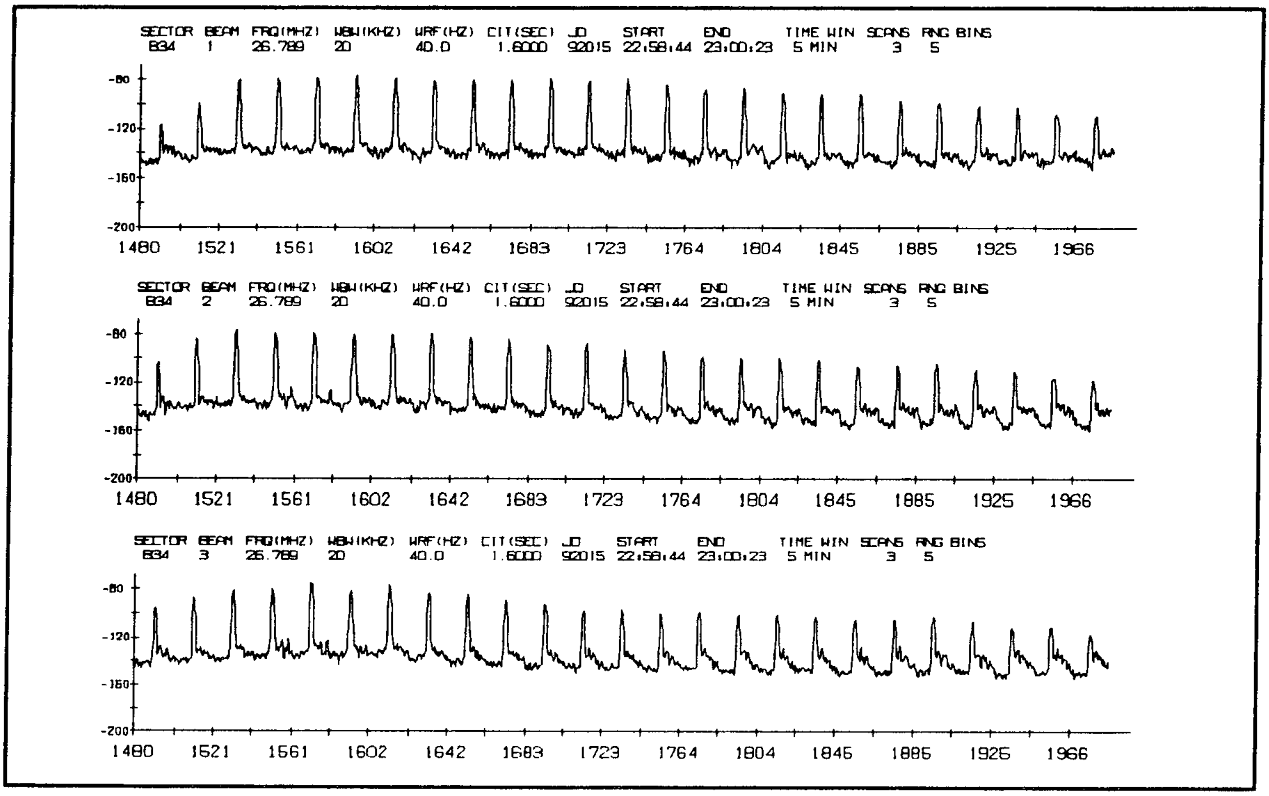


Figure 13 Inner Noise

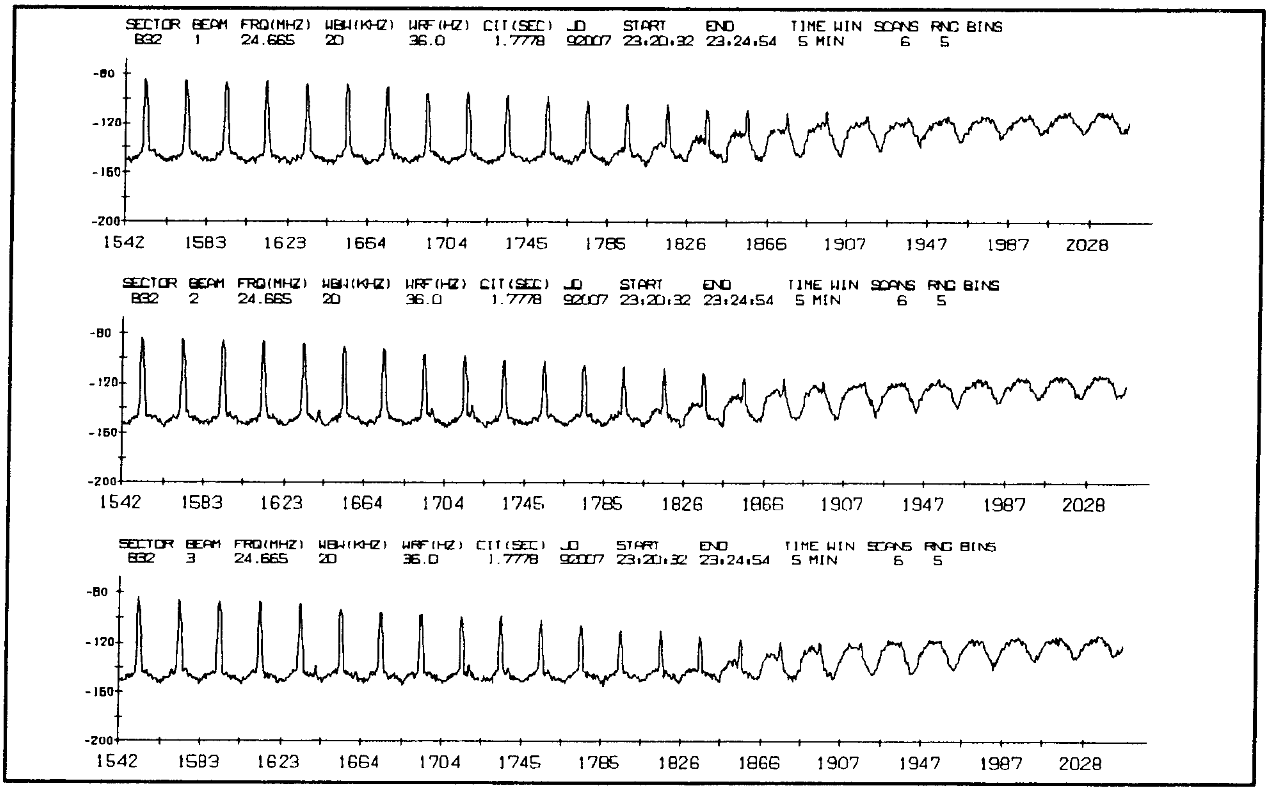


Figure 14 Sloped Noise

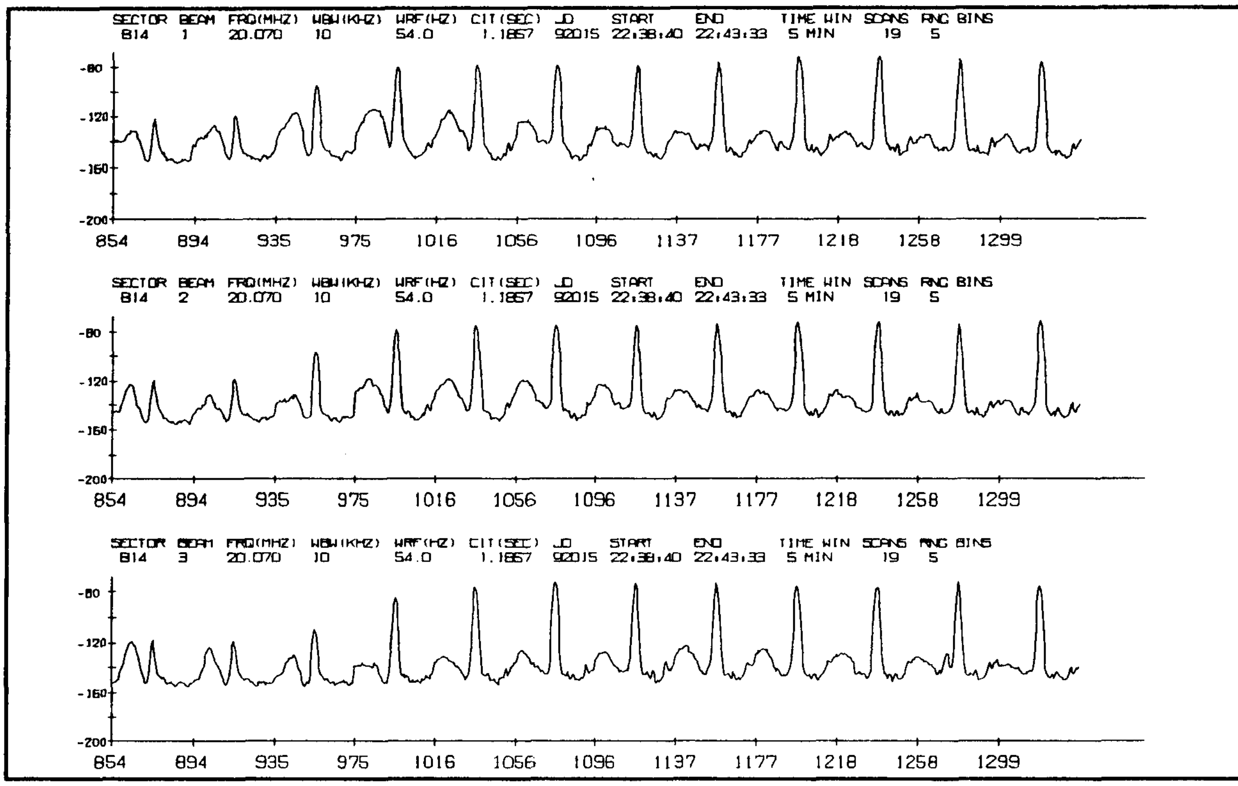


Figure 15 Offset Ionospheric Clutter

2.4.4 Ionospheric Clutter Fit

Once the excision process has been completed, a search is made for the largest remaining data point. The location of this new peak relative to the ground clutter excision window defines two distinct cases:

- The ionospheric clutter peak is offset from the ground clutter excision window by at least two Doppler lines, and the peak value exceeds the value at the edge of the excision window by at least 3 dB.

- The peak is within one Doppler line of the edge of the excision window.

In both cases, a least squares straight line fit is made to the remaining data on each side of the new peak. This yields a triangle representation of the ionospheric clutter.

2.4.4.1 Offset Ionospheric Clutter

In the case of offset ionospheric clutter, the actual peak value and location are known. Consequently, the two straight line fits are forced through the peak data point. In addition, the fitted lines must not extend into the noise excision region. If this condition is violated, the best

fit lines are forced through the point at the edge of the noise excision region.

Once these fits have been made, the line that increases approaching the edge of the excision window nearest the ionospheric clutter peak (i.e., the left line if the new peak is on the left of the excision window, or the right line otherwise) is extended to the excision window border. If the fitted line does not exceed the original data value at the window border by at least 3 dB, the "offset" fit results are dropped and the "coincident" fitting approach is used (see Section 2.4.4.2).

2.4.4.2 Ionospheric Clutter Peak Coincident With Ground Clutter

When the ionospheric clutter peak borders the excision window, our assumption is that the ionospheric clutter peak is actually located within the ground clutter excision window. Since the actual peak value is not known in this case, the two straight line fits are unconstrained. After the two fits have been made, the intersection of the two lines is found. If the intersection lies within the ground clutter excision window, then no further processing is required.

A correction is made if the intersection point of the two straight fit lines lies outside the ground clutter excision window, since this is not consistent with the initial assumption that the ionospheric clutter peak lies inside the ground clutter excision window. In this case, the straight line fits are truncated at the ground clutter excision window boundaries, and the largest fitted point at the edge of the excision window is taken as the ionospheric clutter peak.

3. APPLICATION

3.1 AUTO-PROCESSING RESULTS

3.1.1 Introduction

The results of our processing algorithm are applied to various types of ARD data. In addition to "best case" data, we illustrate the algorithm's limitations with the inclusion of some typical problem cases.

In the figures that follow, processing results are displayed as overlays on the averaged ARD data. Ground clutter peaks are marked with an "x", and the ground clutter excision window boundaries are indicated by vertical lines. Two error terms have been calculated for each processed range cell. These terms indicate the root mean square error for the left and right sides of the ionospheric clutter fitting region (separated by the ground clutter peak). An errors of 0.0 does not suggest a perfect fit, but indicates that no fit was performed in the corresponding region. This happens when all data is removed by the ground clutter and noise excision steps.

3.1.2 Processing Samples

Figures 16, 17, and 18 show some typical processing results. The ionospheric clutter in Figure 16 is moderately strong, and is centered around the ground clutter. The fit is extremely good in this example. Figure 17 exhibits strong ionospheric clutter, particularly in beams 1 and 2. Much of this clutter is centered on the middle of the Doppler cells, although in several cases it is shifted slightly to the left. In either situation the results of the fit are quite acceptable. Figure 18 is an example of unusually strong, fairly broad ionospheric clutter. As in the previous case, the location of the ionospheric clutter peak varies. Again, the fit is seen to be quite good.

In Figure 19, particularly good fits are seen in the first six range cells of beam 1. At the longer ranges, the data outside the excision window is replaced by the median elevated noise level due to the lack of narrow band ionospheric clutter in this region. A shortcoming in the processing algorithm is seen in several of the range cells in beams 2 and 3. As a result of an improper median noise level determination, noise level replacements have occurred where ionospheric clutter was clearly present. Since the ionospheric clutter is located at the range cell boundary, an offset processing range was required and the lowest noise values did not satisfy the "clustering" requirement for inner noise, as discussed in Section 2.4.2.

Figure 20 illustrates some typical problems encountered when the ionospheric clutter peak is offset from the ground clutter peak. Unlike the case shown in Figure 19, the ionospheric clutter fits must span the excision window in most range cells. The results are good when the data on the far side of the excision window is sufficient to "tie down" the fit, as in the second range cell of beam 3. Otherwise, the fit is not sufficiently constrained, producing results such as those at the longer ranges in beam 1.

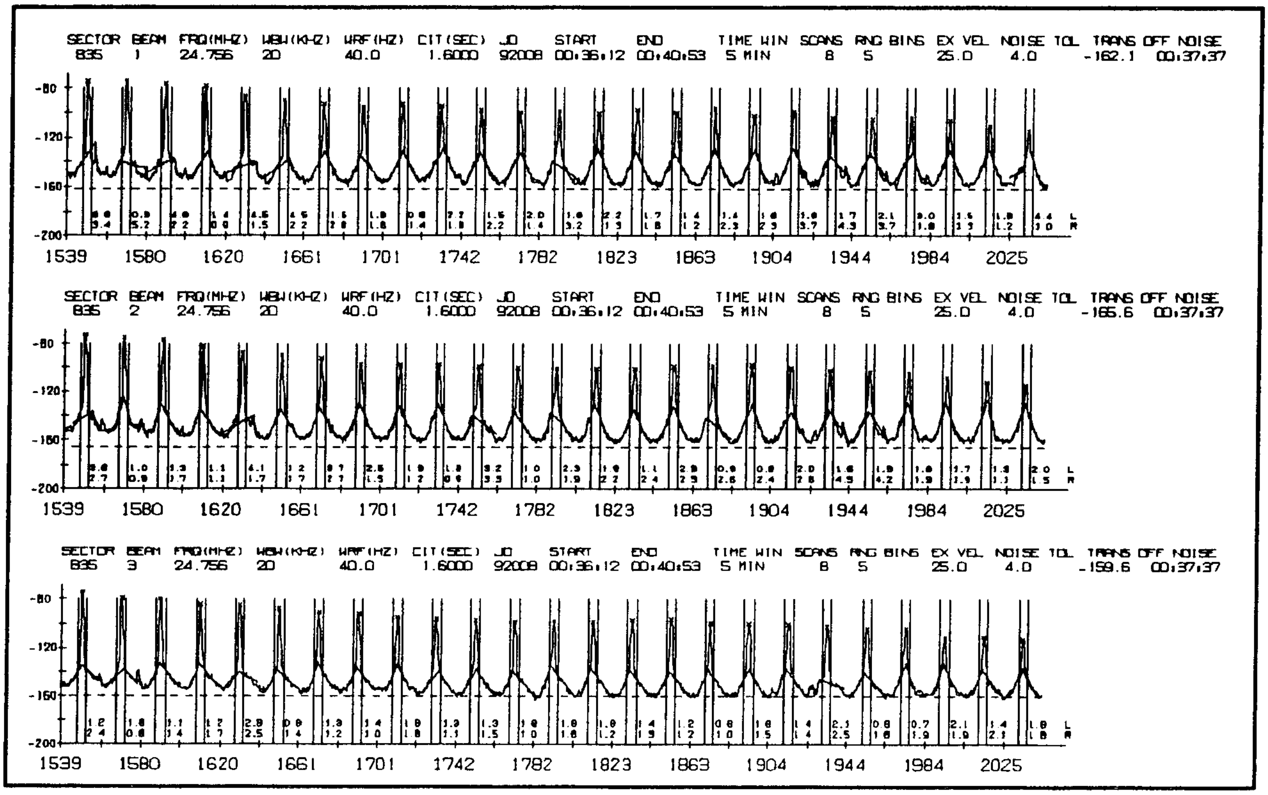


Figure 16 Moderately Strong Ionospheric Clutter

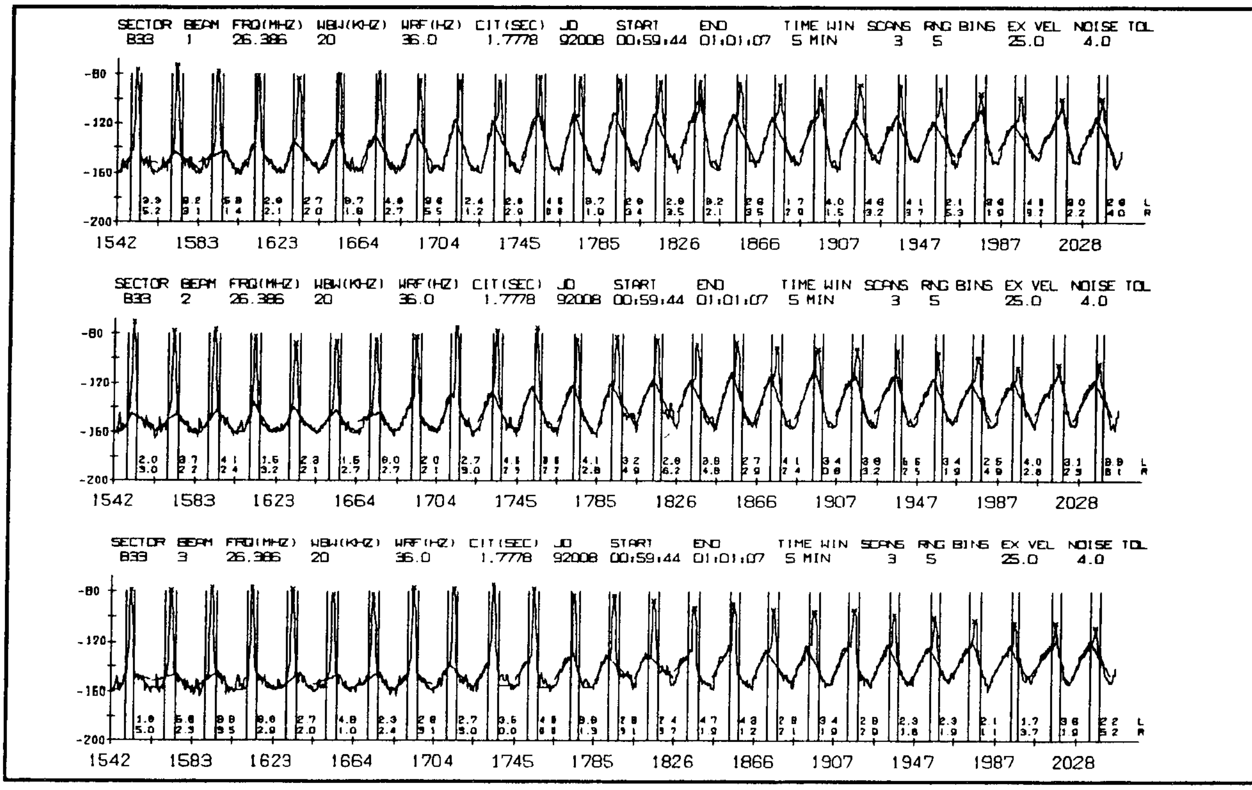


Figure 17 Strong Ionospheric Clutter

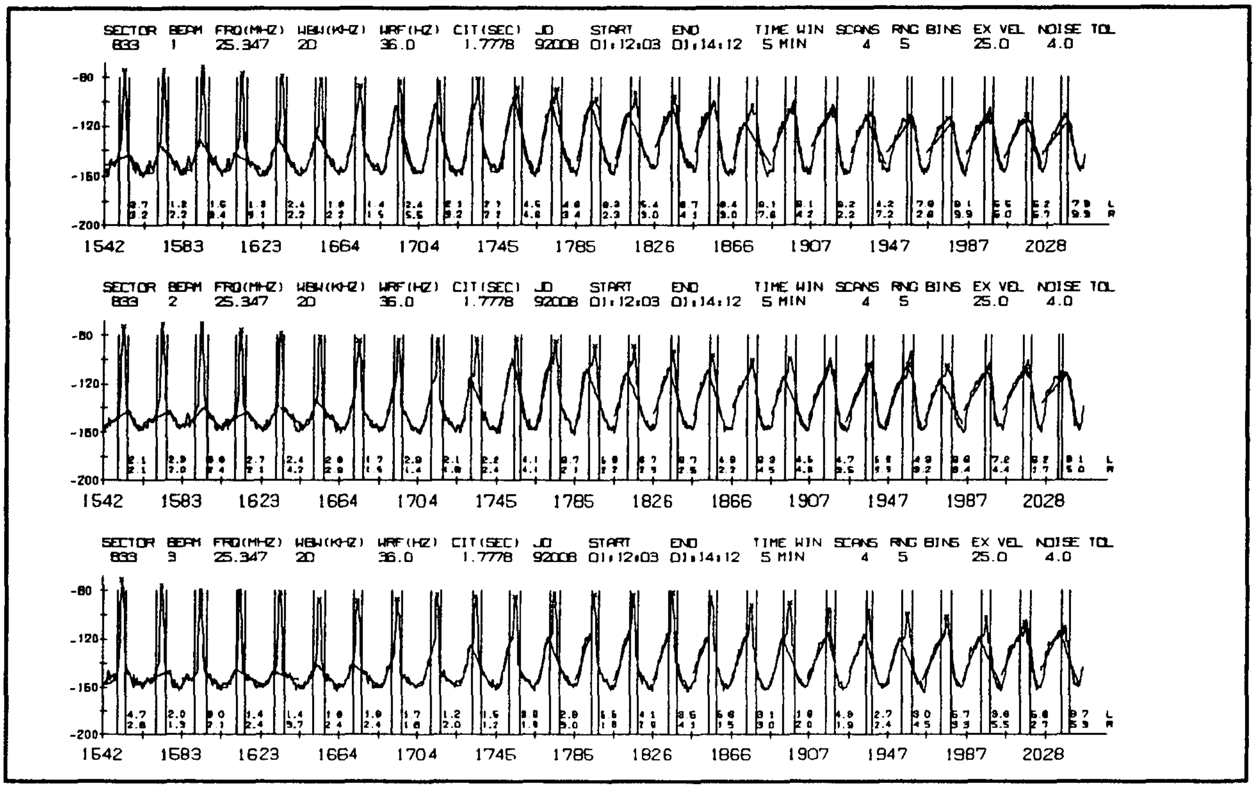


Figure 18 Extremely Strong Ionospheric Clutter

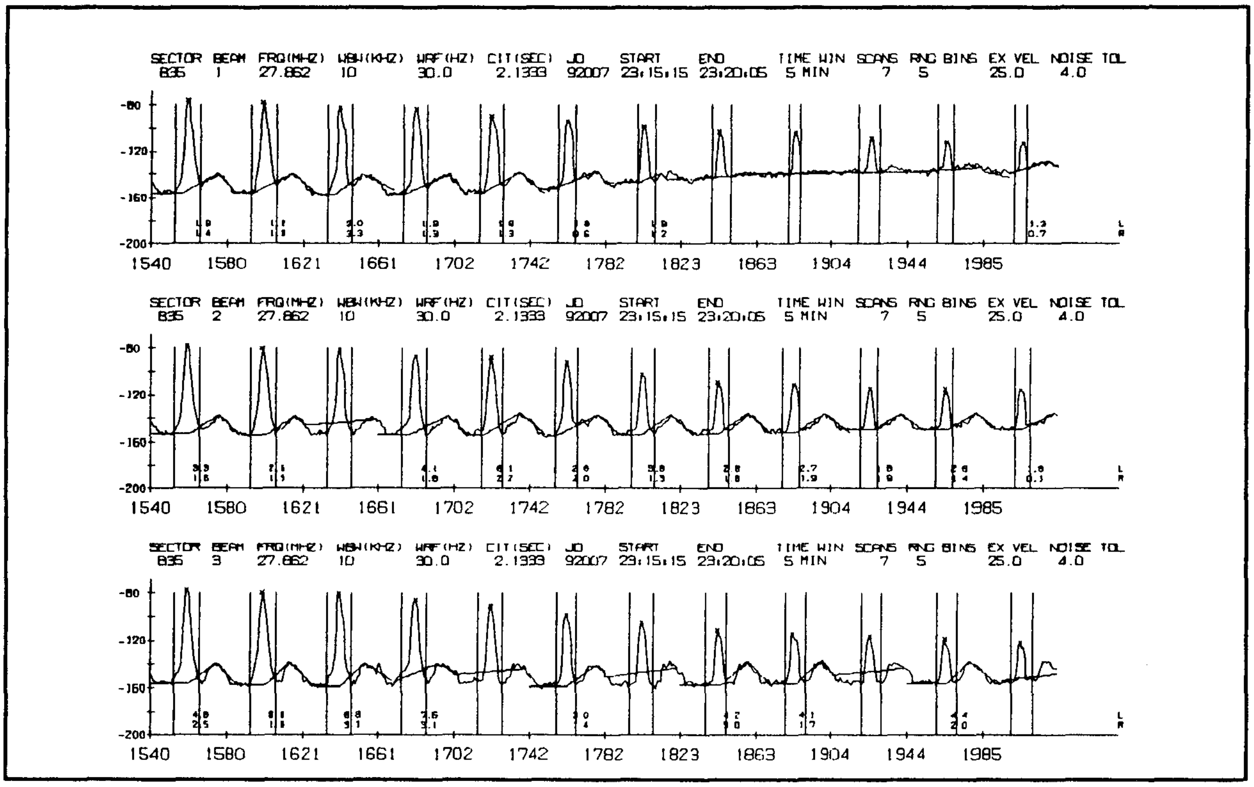


Figure 19 Improper Noise Level Example

In Figure 21 we see excision of all data in the shorter ranges of all three beams, as a result of clearly defined ground clutter in combination with flat noise regions. This is the desired result, since there is no significant ionospheric clutter present in this data. The transmitter-off noise levels are indicated by the dotted lines. Note also that the algorithm does not perform any ground clutter excision in several range cells, notably the last three range cells of beam 2.

The example in Figure 22 shows a data set requiring a more sophisticated algorithm than our present model. Specifically, the right sides of the ionospheric clutter regions show two or three distinct peaks. The use of a single slope results in a compromise. However, the model results shown are clearly good straight line fits, and the increased accuracy that might be obtained with multiple slopes would not necessarily be of benefit to our synoptic study.

The final processing problem example, Figure 23, shows the result of restricting the ground clutter peak search to the middle region of the range cell. Here, the range cells in beam 1 between 1777 and 1919 nm contain other peaks that are noticeably higher than the identified ground clutter peaks. Notice that with this restriction on the ground clutter peak search, the measured ionospheric clutter amplitude remains fairly constant throughout the scan, while the ground clutter amplitude decreases dramatically as range increases. Without the restriction on the search, ionospheric clutter would have been removed, and the straight line fits would have been made to ground clutter data.

3.1.3 Summary of January, 1992 Processing Results

Table 1 presents a summary of the processing of all available data from the January, 1992 campaign. Statistics are tabulated for each tape (as received from the ECRS), with the starting day and universal time of each batch of data given in the first two columns. "Processed sides" indicates the number of straight line fits calculated, while "unprocessed sides" gives the number of ionospheric clutter fragments for which no fit was attempted. The mean error and standard deviation terms shown do not include these unprocessed areas.

3.2 DERIVED ARD PARAMETERS

Several ARD data characteristics have been defined in addition to the basic set discussed in Section 2.3. Most of these parameters can be easily computed from the ionospheric clutter fits discussed in Section 2.4.4.

- Clutter to noise ratio (CNR) - the difference between the ground clutter amplitude and the median noise level. This provides an indication of the quality of the radar system's performance.

- Ionospheric clutter ratio (ICR) - the difference between the ionospheric clutter amplitude and the median noise level.

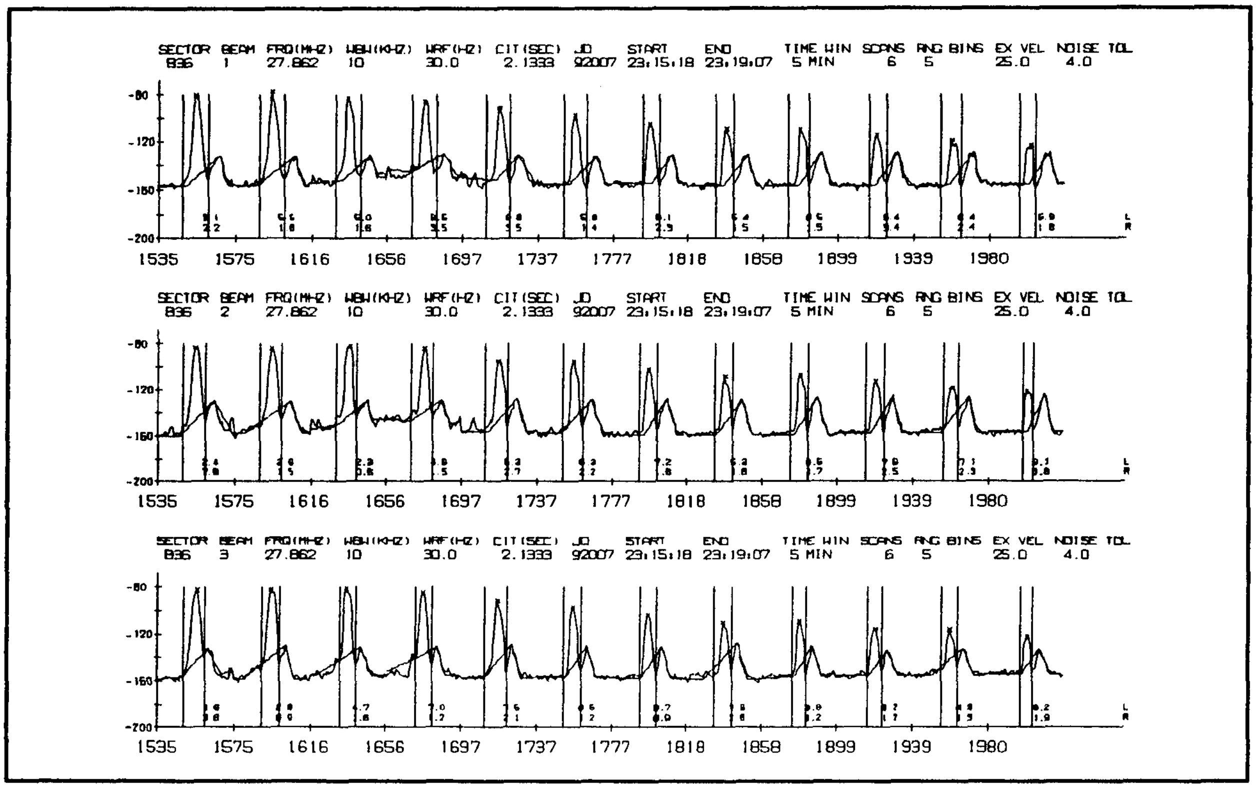


Figure 20 Offset Ionospheric Clutter

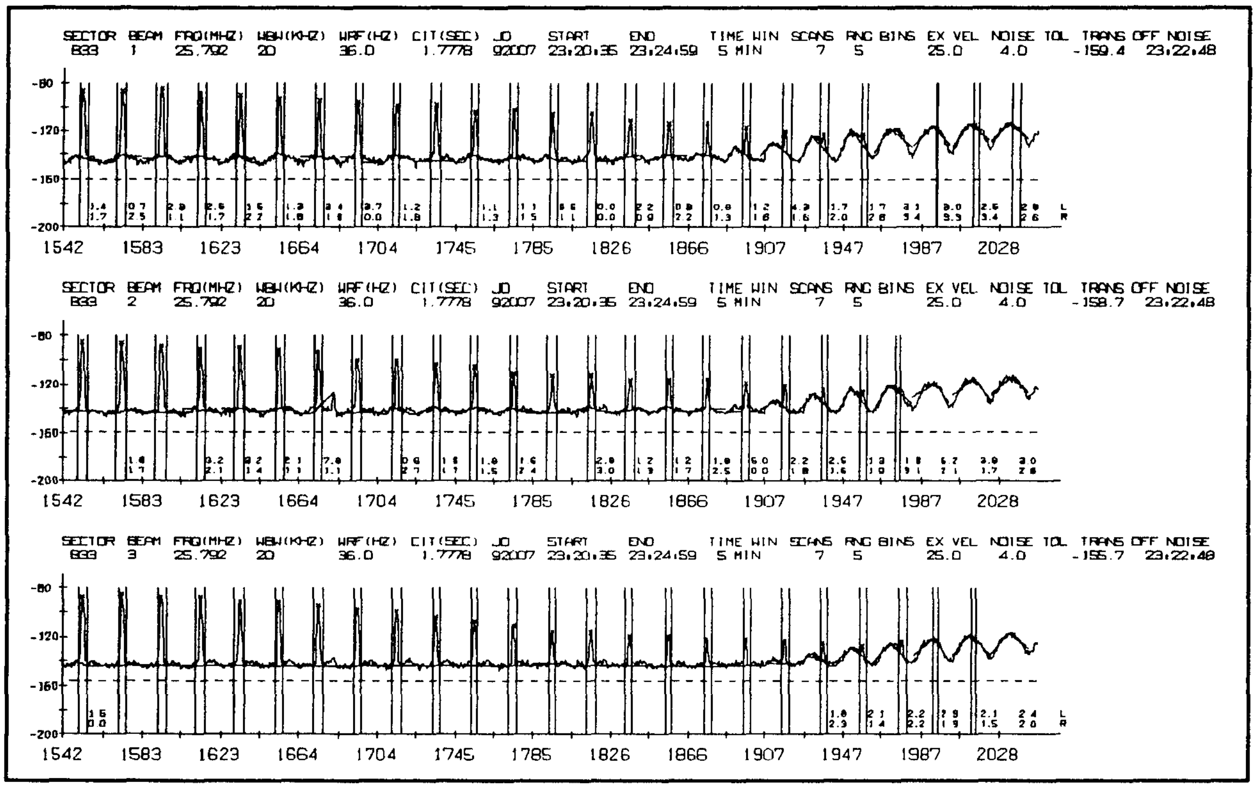


Figure 21 Total Data Excision

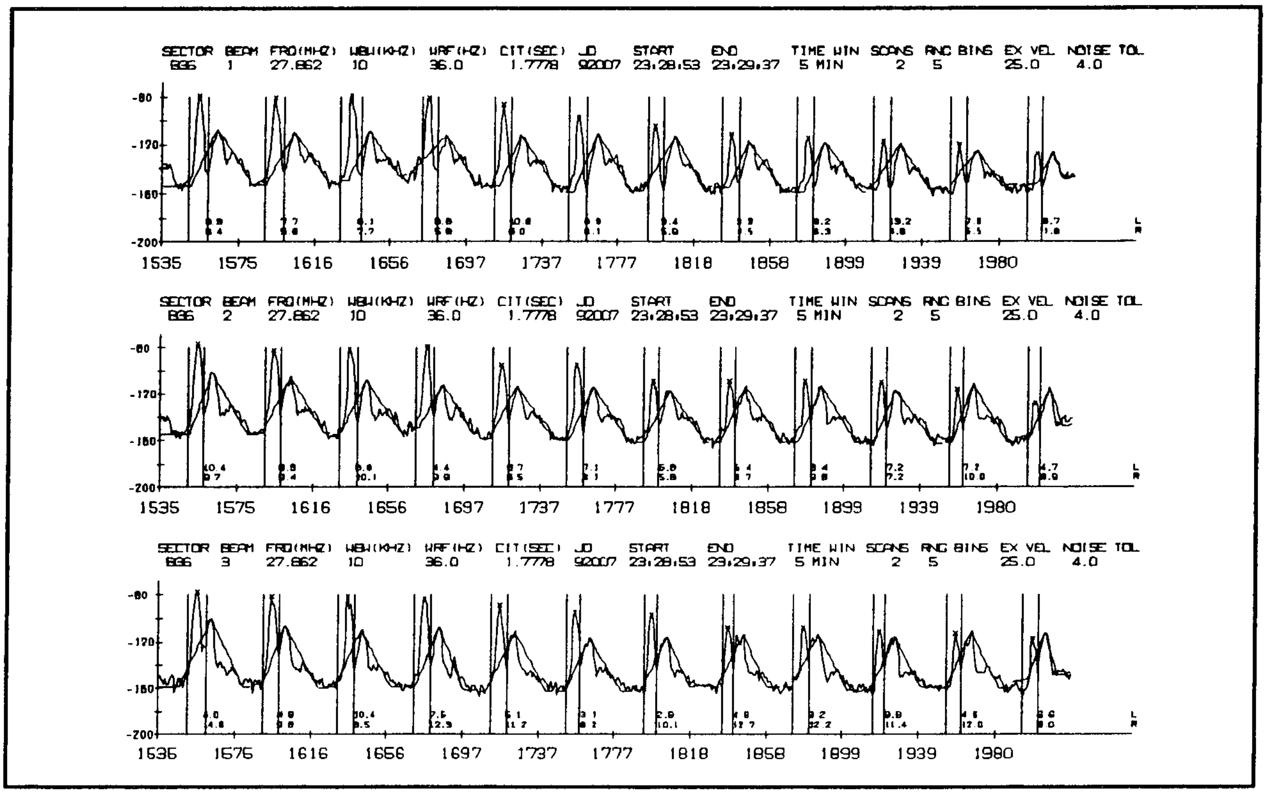


Figure 22 Ionospheric Clutter With Multiple Peaks

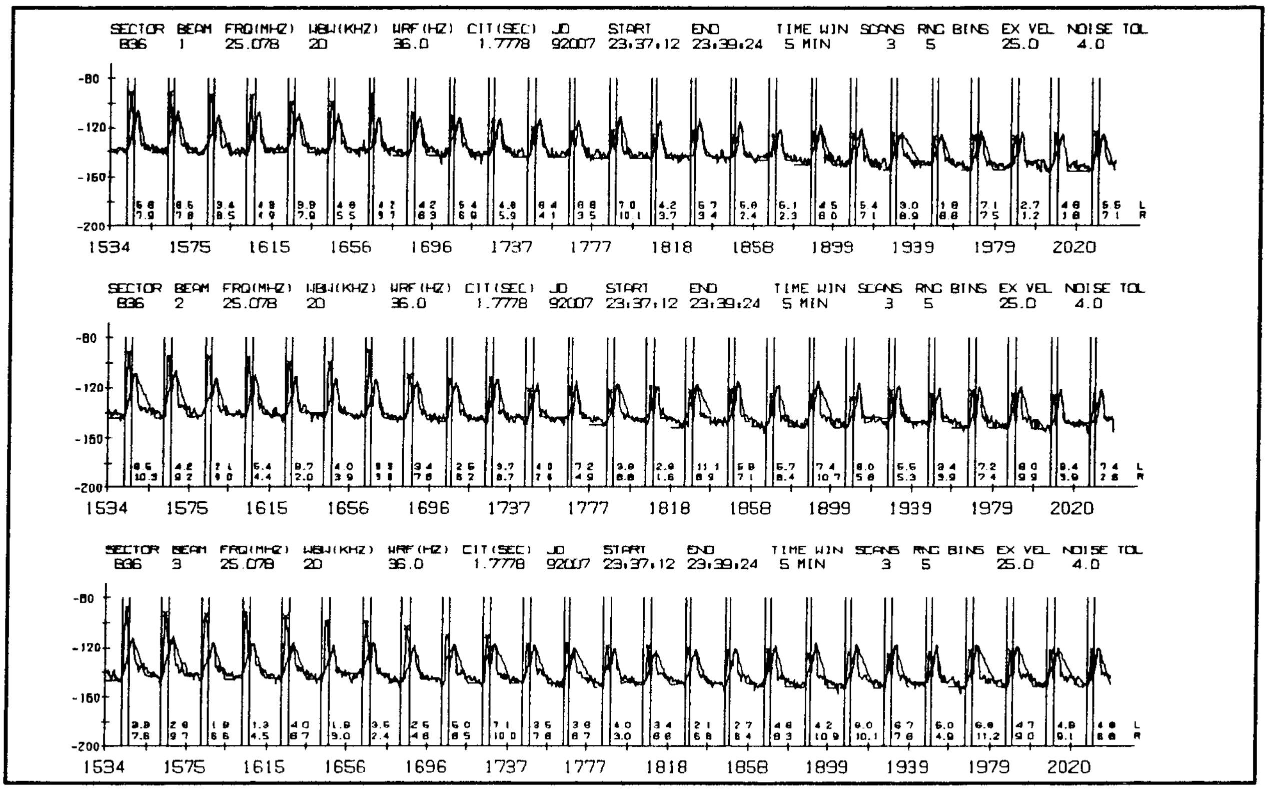


Figure 23 Restricted Ground Clutter Peak Search

Table 1 January, 1992 Processing Summary

Day	Start Time (UT)	Total Number of Range Cells	Processed Sides	Unprocessed Sides	Mean Error	Standard Deviation
007	2149	6234	11885	583	2.614	2.143
007	2313	5308	10196	420	2.568	1.761
008	0035	3511	6808	214	2.391	1.451
008	0118	3717	7263	171	2.547	1.776
008	0209	7855	15049	661	2.203	1.482
008	0358	8184	15866	502	1.950	1.203
008	2240	6106	11563	649	2.526	1.875
008	2352	4952	9484	420	2.265	1.622
009	0106	6786	13040	532	2.859	1.990
009	0237	5412	9717	1107	2.436	1.868
009	2211	3153	5799	507	2.270	1.808
009	2319	3889	7455	323	2.378	1.709
010	0025	4213	8269	157	1.945	1.162
010	0132	6314	12577	51	2.212	1.265
010	0242	6241	12331	151	2.160	1.231
010	2221	2624	4765	483	2.405	1.971
010	2330	3756	6979	533	1.954	1.347
011	0041	4931	9455	407	2.282	1.391
011	0158	5580	10878	282	2.242	1.318
011	0315	4546	8577	515	2.384	1.527
011	2148	6171	10987	1355	1.934	1.628
011	2328	4577	7956	1198	2.209	1.792
012	0055	6118	11228	1008	2.471	1.851
012	0216	6888	12591	1185	2.597	1.912
012	2231	4466	8211	721	2.486	2.056
012	2331	5837	10985	689	2.193	1.446
013	0038	3949	7454	444	2.581	2.296
013	0143	2398	4758	38	2.965	2.491
013	0250	5019	9627	411	2.218	1.592
013	2308	4977	9338	616	2.220	1.764
014	0011	5899	11454	344	2.053	1.133
014	0114	5539	11029	49	2.255	1.397
014	0218	4489	8855	123	1.867	1.126
014	2221	3561	6514	608	1.972	1.622
014	2326	4033	7650	416	2.320	1.551
015	0030	5391	10324	458	2.304	1.474
015	0136	3928	7162	694	2.084	1.329
015	0243	4946	9621	271	2.130	1.302
015	2228	3684	6601	767	2.465	1.783
015	2313	4633	8398	868	1.877	1.218
016	0011	5774	11212	336	2.056	1.219
016	0114	5738	11408	68	1.928	1.069
016	0215	6438	12861	15	2.567	1.350
016	2328	3364	5925	803	2.317	1.994

- PIGR - the difference between the ground clutter amplitude and the ionospheric clutter amplitude.

- Excess noise level - the difference between the median noise level and the transmitter-off noise level. This value is used to measure the component of the noise that occurs as a result of radar system operation.

- Ionospheric clutter width - the difference between the left and right clutter fits at a level 10 dB below the ionospheric clutter peak, measured in m/s.

- Total Power - this is computed as the area under the ionospheric clutter curve. The gain values must be converted out of dB before making this calculation, since dB is a logarithmic scale.

4. CONCLUSIONS

The auto-processor developed here is only a tool for the analysis of a large volume of OTH ARD data, that can be used to understand the characteristics and origins of equatorial clutter as seen by the radar. It was not intended to develop a processor that was 100% accurate. The philosophy used here was that an effective tool would work about 80% of the time, and the synoptic averaging of the data set would take care of any remaining processing errors. With this is mind, a sample of eight hours of data from the January, 1992 ECRS campaign is used to illustrate the potential of this auto-processor software.

4.1 SAMPLE SYNOPTIC DATA

The eight hour radar operation beginning at 2100 UT on January 7, 1992 was selected as typical, and is used here to illustrate the capabilities of this auto-processor. No human intervention was used on this data sample, and the presented results are based solely on the output of the auto-processor.

Figure 24a shows the time variation of ionospheric clutter intensity over the active radar azimuths in Segment III, from 2100 UT on the 7th of January through 0400 UT on the 8th of January. In order to obtain this plot, all auto-processed range bins were combined by averaging, on the assumption that the basic structure of the ionospheric clutter does not vary significantly over the 518 nm interval. The figure shows the amplitude of the ionospheric clutter peak using color to indicate the intensity (see the legend). Superimposed on this plot are the local sunset and midnight times, to serve as a reference for the observed phenomena. It was assumed, in generating these sunset / midnight curves, that the source of the ionospheric clutter lies in a region some 8000 Km from the radar near the dip latitude contour of 20° S, i.e., along the shaded region shown in Figure 25. The justification for this assumption will be presented in a follow-on report on the synoptic analysis of the OTH ARD data.

For this day, and typically for many days, a period of strong clutter is observed associated with the sunset terminator moving across the coverage region of the radar. This agrees with the radar operators' observations that this clutter phenomenon seems to begin around sunset and progresses from east to west. A second significant increase in the intensity of the ionospheric clutter begins some hours later, just before midnight. This second event seems to occur over all azimuths of the radar at almost the same time, in contrast to the sunset clutter that moves systematically across the coverage. For this event, the intensity is greatest at the eastern edge of the radar azimuth scan.

Figure 24b illustrates the derived spectrum width of the ionospheric clutter spectrum for each time (5 minutes) and azimuth (2.5°) interval for the same period as for the ionospheric clutter amplitude shown in Figure 24a. It is apparent that the periods with the largest ionospheric clutter amplitudes have the narrowest Doppler spectrum widths, measured in meters / second at a point 10 dB down from the peak. Finally, Figure 26 illustrates the use of the auto-

Figure 24a. Ionospheric Clutter Amplitude Day 92007

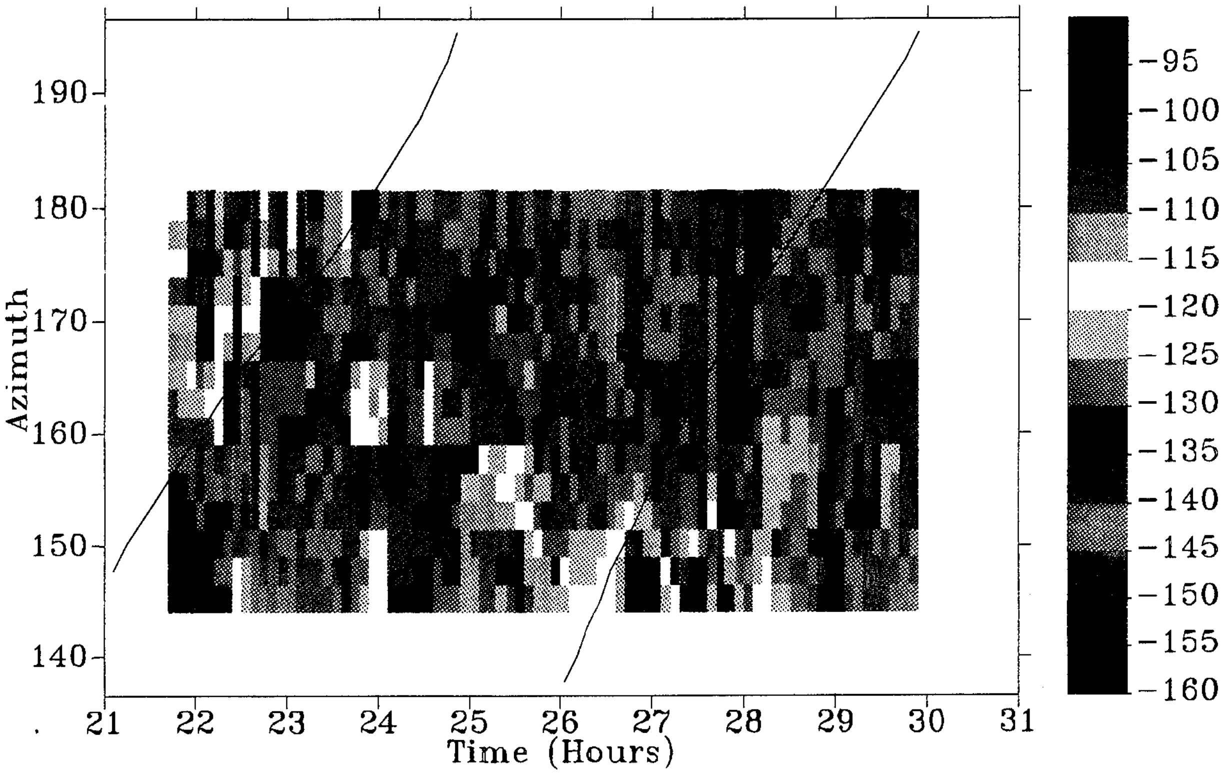
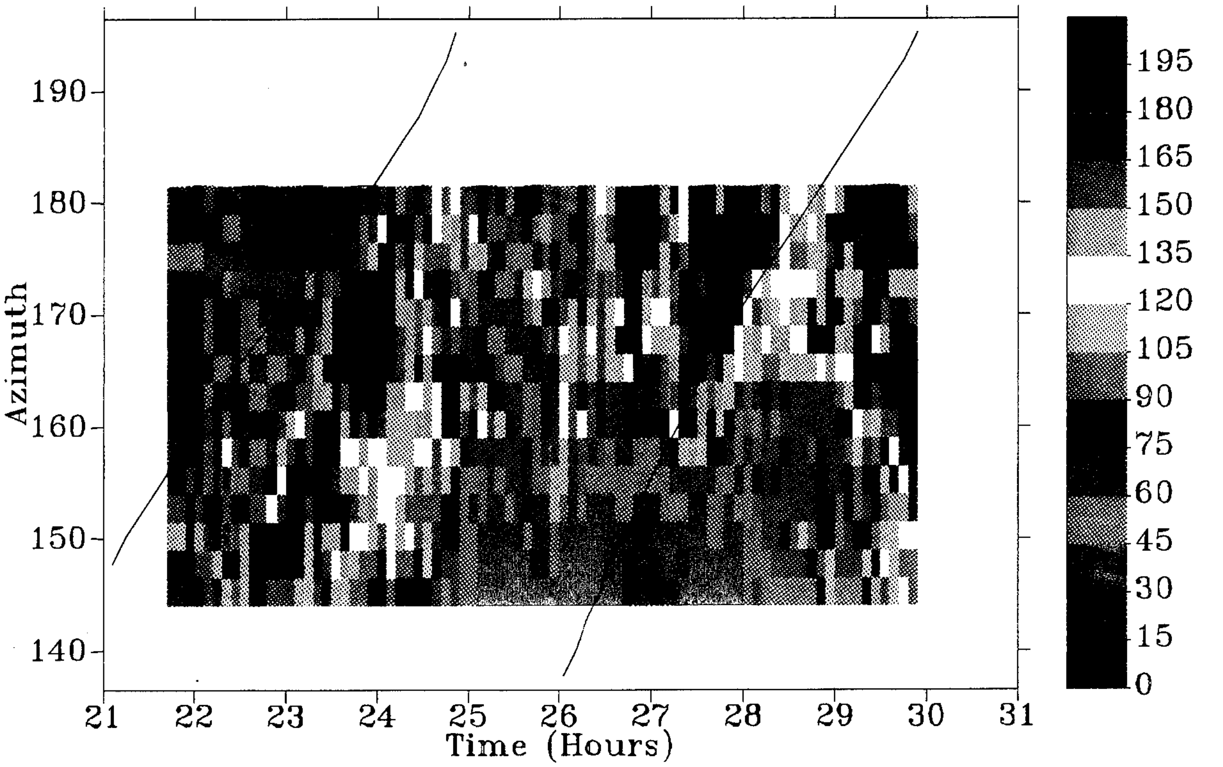


Figure 24b. Ionospheric Clutter Width Day 92007



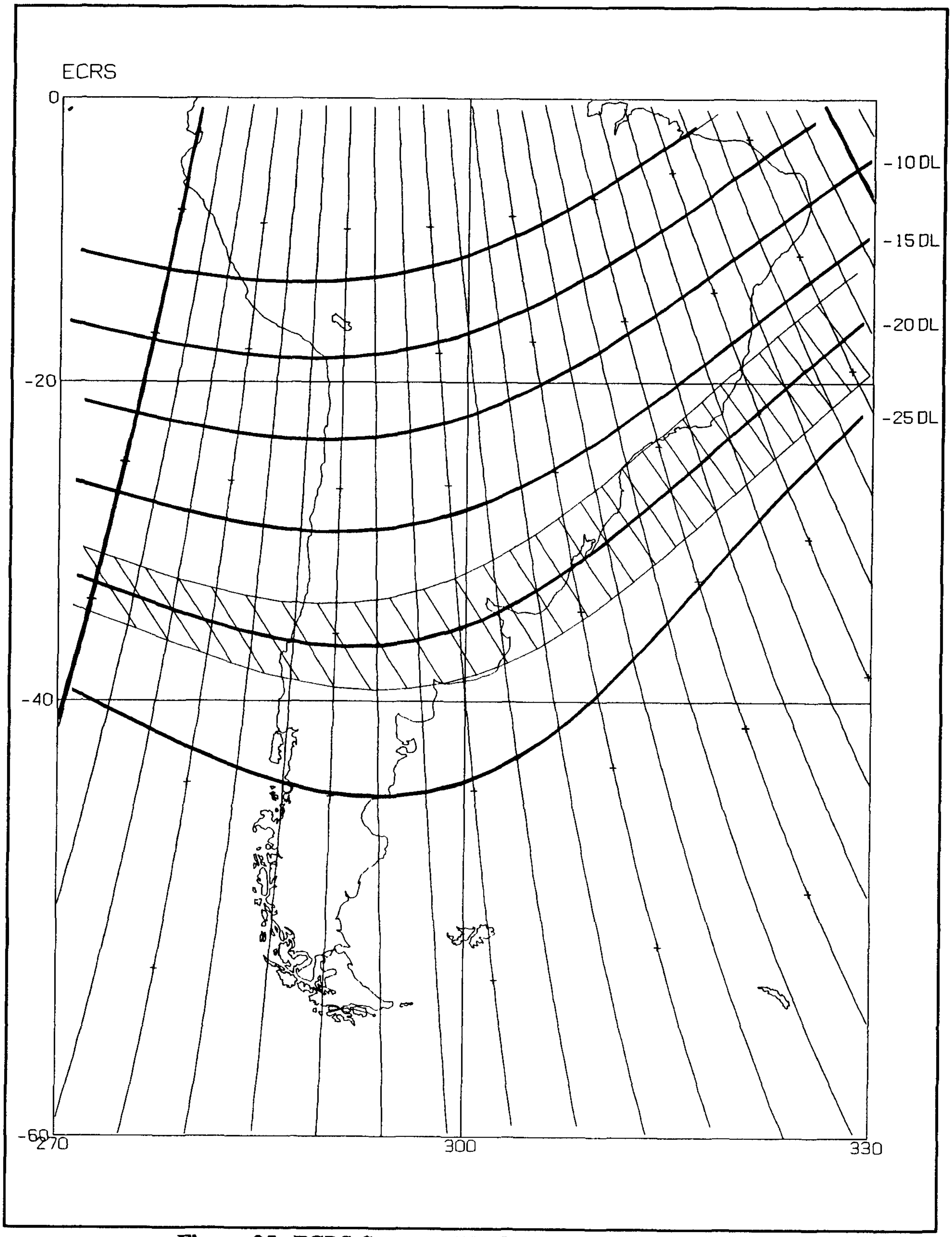


Figure 25 ECRS Segment III - Ionospheric Clutter Source

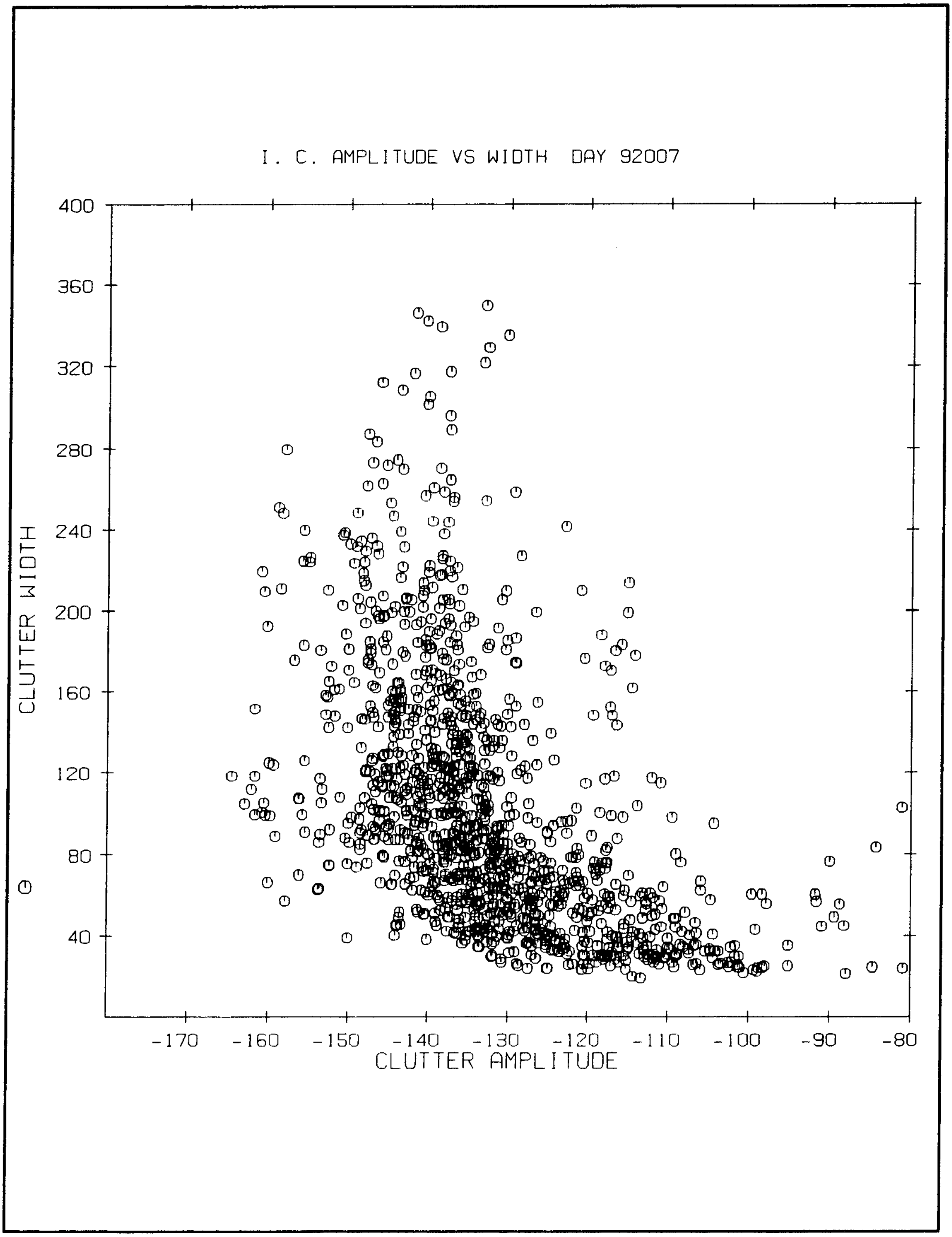


Figure 26 Ionospheric Clutter Amplitude vs. Ionospheric Clutter Width

processed data in a scatter plot of ionospheric clutter amplitude vs. Doppler spectrum width, as defined above, for 7/8 January, 1992. This figure indicates the high anti-correlation between these two parameters.

This is just the beginning of the analysis of these data, and much more detail will be found in a future technical report. This subsequent report will present the actual application of this auto-processor to nine consecutive days of radar data.

REFERENCES

Reynolds, D. S., "OTH Tape Processing and Data Analysis Software", Radex, Inc., Bedford, MA, January, 1993.

Sales, G. S., "Scattering From A Three Dimensional, Anisotropic Random Medium", First US/Australian Joint Study Working Group Meeting (JSGM) on OTH Radar Research and Development, MITRE Corp., Bedford, MA, August, 1992.